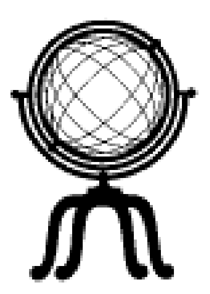




Madeira, Sugar, and the Conquest of Nature in the "First" Sixteenth Century

Part I: From "Island of Timber" to Sugar Revolution, 1420–1506

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> In the long march toward the modern world-system, *mass* commodities—gold, sugar, slaves, cotton, coal, oil—have been its beasts of burden. They have sometimes served as markers for entire historical epochs.... They are the motors of production, the ultimate hard currency of exchange (Retort, 2005: 39).

Madeira is a small island with a large place in the origins of the modern world. Lying some 560 kilometers west of North Africa, Madeira was home to the modern world's first cash crop boom, a sugar revolution. In the second half of the fifteenth century, the Portuguese Crown, Italian and Flemish capitalists, and Canarian and African slaves converged on this modest island to organize a commodity revolution that would catapult Madeira to the commanding heights of the European sugar economy. Cyprus had never produced more than 800 tons of sugar, and this figure had taken centuries to achieve; from almost nothing at mid-century, by 1500 Madeira outproduced its closest competitor by a factor of 6:1 (Maddison, 2001: 58). Madeira's decline was no less rapid. The island's sugar production peaked in the first decade of the sixteenth century; by 1530 output had fallen by 90%. The furious pace of transformation, on both sides of the peak, can hardly be overemphasized. It is this, more than anything else, which distinguishes Madeira from its medieval forerunners.

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In what follows, the first of two successive articles in this journal, I explain how this epoch-making acceleration of boom and bust on Madeira, during Braudel's (1953) "first" sixteenth century (c. 1450–1557), marked a new crystallization of the nature-society relations pivotal to the rise of capitalism. The endless accumulation of capital, in this reading, is the endless conquest of nature. The very conditions of Madeira's rapid ascent were the conditions of its rapid decline. These stemmed from the rapid organization, and consequent exhaustion, of the relations governing human and extra-human nature: labor and land. These relations allowed for the rapid advance of sugar at the expense of the forest; in time, deforestation undermined the sugar regime's capacity to reproduce itself.

This first sugar revolution was local but not local*ized*. It was constituted by new flows of capital, power, and nature whose convergence marked an epochal shift in human history. The intention is, therefore, only partly one of excavating the "environmental history *of*" Portuguese colonialism and seaborne expansion. A more fundamental task is posed by what I call "environmental history *as*." Here, the challenge is to reveal Portuguese expansion *as* environmental history, *as* a socio-ecological project and process aimed at establishing new rules of reproduction for the relations of humans and the rest of nature. In the first article (Part I of this essay), I examine the conditions and transformations of Madeira's sugar revolution. I show how the rapid appropriation of biophysical wealth was vital to the sugar boom, and that the apex of this boom (c. 1490–1510) reveals the historical limits of this expansion. This analysis sets the stage for my account, in the second article (Part II of this essay), of Madeira's crisis—manifested in a 90% contraction of sugar production between 1506 and 1530.

SUGAR IN THE CAPITALIST WORLD-ECOLOGY: THEORETICAL FRAMES

Sugar, we know quite well by now, was wrapped up in the making of early capitalism, pivotal in the formation of the slave trade, precociously industrial in its agro-ecological organization, important as a source of investment capital for the Industrial Revolution, dynamic in its interweaving of production and consumption

relations in everyday life (Mintz, 1985; Blackburn, 1997; Galloway, 1989; Schwartz, 2004; Sheridan, 1973; Tomich, 1990). But just what, pray tell, does the history of sugar tell us about historical capitalism as world-ecological process and project?

Sugar revolutions in the long transition to capitalism issued two relentless facts. One was about human nature as labor power; another was about extra-human nature as resource. The first, and best recognized, is the intimate connection between sugar, slavery, and the plantation. No history of modern slavery is complete without sugar, and no world-historical reckoning of sugar can escape the pivotal role of Madeira—even if historians of sugar and slavery find little agreement on just how *modern* Madeira really was (Greenfield, 1977; 1979; Verlinden, 1970; Solow, 1987; Curtin, 1990; Galloway, 1989; Mintz, 1985; Vieira, 2004).

Our second fact turns on the contradictions inscribed in the endless commodification of global nature. Amongst environmental historians, Madeira's claim to fame rests on the island's deforestation (Crosby, 1986; Perlin, 1989; Williams, 2003; Grove, 1995; 2002; Moore, 2000b), for these scholars the surest sign that a new mode of producing nature had arrived. The modern story of sugar is the story of capitalism's inexhaustible appetite for human and extra-human nature in servitude to the commodity form. To speak of sugar as "mass commodity" (Retort, 2005: 39) is to highlight its production of nature, its capacity to extract as much as possible, as quickly as possible, from local environments—and then, to move on. To say that sugar was a mass commodity is to say, in other words, that sugar was also a commodity *frontier* that capitalism developed *through* the socio-ecological crises that attended every sugar complex, *not in spite of them.*

Madeira is, in other words, bound up with two great historiographical and theoretical debates, one turning on the transition to capitalism, the other, on the origins of today's socio-ecological crises. The two debates reflect a singular historical process: the rise of capitalism as a profound rupture with pre-modern patterns of nature-society relations (Moore, 2000a; 2000b; 2003a; 2003b; 2007). It is my intention to move beyond the grafting of social and economic history onto environmental history, and vice versa (e.g., Taylor, 1996), in favor a synthesis premised on the production of nature, the accumulation of capital, and the pursuit of power as differentiated moments within a singular world-historical process.

That process I take to be the modern world-system (Wallerstein, 1974), which is, in my view, a capitalist *world-ecology* (Moore, 2003c; 2007; 2008; 2010a; 2010b; 2010c; forthcoming a; forthcoming b). In world-ecological perspective, historical capitalism does not *act upon* nature so much as *emerge and develop through* the dialectic of human and extra-human nature. Far from a social force that imposes its terrible "footprints" upon a passive and external nature, the world-ecological perspective offers a different way of seeing, viewing capitalism as a symbolic and material matrix, co-created through the activities of humans with the rest of nature. The term I use to capture this relation—so often misstated as the nature-society dialectic, as if the categories themselves were somehow formed independently of one another—is *ecology*. But where "ecology" is often deployed interchangeably with "environment" and "nature," I draw inspiration from the Greek philosopher and botanist Theophrastus' rendering of *oikeios*, to refer to the *relation* between a plant species and its environment (Hughes, 1994: 4). The (so-called) dialectic of "nature" and "society" are the *results* of this relation, the *oikeios*, not its point of departure (Moore, forthcoming a). Capitalism, from this standpoint, does not *have* an ecological regime. It *is* an ecological regime—a complex, contradictory, and utterly messy bundle of human and extra-human natures.

I have indicated that Madeira's place in the modern world-system is typically approached from one of two perspectives. The perspective of social history focuses on sugar and slavery (Verlinden, 1970; Curtin, 1990; Galloway, 1989; Greenfield 1977; 1979; Solow, 1987; Vieira, 1995; 1996; 2004). The perspective of environmental history focuses on landscape changes (Crosby, 1986; Grove, 1995; 2002; Perlin, 1989; Williams, 2003). Ontologically, these two ways of writing history flow from a singular way of seeing the world. In this Cartesian optic, human nature, the stuff of class struggles and world markets and imperialisms, goes into one box; extra-human nature, the stuff of forests and soil and rivers, goes into another. The agencies within each box interact, but their relations do not change the boxes themselves. In other words, for social and environmental historians both, the relations between these two historical moments are consequential, *but they are not constitutive.* For instance, no one has yet argued for a reconceptualization of modern slavery *as* a socio-ecological process. The difficulty with the Cartesian binary is that it obscures the really decisive bundles of

relations. On the one hand, the social historians study the origins of the plantation complex, with little concern for its biophysical consequences (e.g., Curtin, 1990). On the other hand, the environmental historians examine the landscape changes issuing from European colonialism and the sugar frontier, but with little analysis of the relations of power and production inscribed in the latter (e.g., Galloway, 1989). Is there not an opportunity here, to see the rise of the plantation complex–indeed the rise of capitalism–as a socio-ecological project?

How then might we rework Madeira's sugar cycle as constitutive–and not simply derivative–of the rise of capitalism as world-ecology? The approach on offer views the political ecology of the island's successive cash crops–timber and cereals, then sugar and wine–as irreducibly multilayered. These commodity regimes were, to be sure, instantiations of the political ecology of Portuguese empire, and of an emergent capitalism. And yet, to emphasize the many scales of modern environmental history is a far cry from writing top-down history. World-systemic and world-scale processes are analytically distinct; indeed a central premise of the world-historical perspective is that transformations of the body, of the labor process, of households, of cities, regions, and states are *all* constitutive of historical capitalism.[1] Madeira's sugar revolution was no global derivation. Its socio-ecological transformations took shape out of the manifold contradictions of the late medieval crisis (see Moore, 2007: ch. 1), and Madeira's transformation in turn shaped the conditions and contours of imperial power and capital accumulation–above all, Portugal's "urgent imperialism" (Pereira, 2006) and the initial formation of the capitalist Atlantic in the first sixteenth century. It was an ongoing movement. Madeira's sugar revolution may have been a one-time affair, but it was not merely the product of one-time conquest and plunder; it was made possible, and then sustained, by an empire and a world-ecology for whom commodity-centered expansion was not simply a way of life, but an existential condition.

[1] The most sophisticated approach that embodies this multi-scalar sensibility is Tomich's classic study of sugar and slavery in Martinique (1990; see also Moore, 2002; 2003b).

THE "ISLAND OF TIMBER": MADEIRA AND THE FATE OF THE FOREST

In the rise of capitalism, sooner or later everything returned to the forest. Every decisive commodity sector in early capitalism—metallurgy, sugar cultivating, shipbuilding, construction—found its lifeblood in the forest. Even cereal cultivation—one thinks of Polish grain flowing to seventeenth century Amsterdam—was bound up with forest clearance on a grand scale (Moore, 2010b). And so it is hardly coincidence that the Portuguese name for the island, "*ilha da Madeira*," translates literally as "island of timber" (Cadamosto, 1937 [1455]: 8). When the first settlers arrived in the 1420's, the Venetian traveler Alvise da Ca' da Mosto (Cadamosto) reports, "there was not a foot of ground that was not entirely covered with great trees" (Cadamosto, 1455: 9). By the 1560's, when the great poet-adventurer Luis de Camões visited the island, he remarked that Madeira, once famed for its sylvan bounty, had long since become an island of timber in name only (Camões, 1996 [1571]: 296).[2]

What happened between the 1420's and the 1560's? In a word, capitalism.

When one encounters the history of Madeira, amongst the first things one learns is the island's origin myth. Like all such myths, it is about nature. The first settlers, confronting an impossibly dense sylvan landscape, set fire to the forest. Cadamosto's is only the most frequently-cited account. "So great was the first conflagration," he tells us, that the first settlers were forced "to flee its fury and take refuge in the sea, where they remained, up to their necks in water... for two days and two nights. By this means they razed the great part of this forest, and cleared the ground for cultivation" (Cadamosto, 1967 [1455]: 9). The fire "took such possession, that it burnt seven years continually, and was seen far off in Smoak and Sparks like *Mount Aetna*; so that afterwards the Island be-

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[2] "We passed the great Island of Madeira,
Called such for its many stands of trees,
[the site] that we first peopled,
[now] more famous for its name than for its glory" (Camões, 1571: 296).

Even earlier, during the 1530's, the timber situation on Madeira was such that João de Barros, in the first volume of *Decadas da Asia*, observed timber scarcity on the island more than two decades before Camões penned his wry comment on Madeira's deforestation (cited in Prestage, 1933: 39).

ing plentiful of Grain, the greatest want the Inhabitants suffered was of Wood, there having been nothing else in it before" (Faria e Sousa, 1695: 4–5).

There was, in other words, a baptismal fire. Like all baptisms, its symbolic power rested in the cleansing of sin, washing away the human hand in the destruction of the island's forests. The fire had escaped human control, and prepared the island, first for the cultivation of cereals, then sugar, then wine. The enduring social power of this origin tale stems from its explanation of the rapid deforestation that did occur during the first century of settlement, and from its explanation of the timber scarcity that beset the island for centuries to come. It was an explanation that enjoyed significant traction—especially amongst English travelers—not least because it located the causes of environmental change in an accident of colonization rather than its systematic (and systemic?) consequence. Thus Samuel Purchas in the 1620's writes that "[i]n the yeere 1420 began that Plantation [Madeira's settlement], and the thicke Trees being... set on fire, continued burning seven yeeres: *which destruction of Wood hath caused since as great want*" (1625: 6, emphasis added). More than two centuries later, J. A. Mason took the same view, noting that "the colony sustained much inconvenience from the want of timber" after the fifteenth century as a result (1850: 156). Madeira's deforestation was, in other words, registered not only in the physical landscape; it was also inscribed in the collective memory of how this landscape was formed.

This origin myth speaks to two salient facts. First, Madeira was indeed deforested rather quickly. Madeira's sugarmills pushed back the forest at unprecedented speed after 1450. By 1510, 160 km^2 of forest, nearly one-quarter of the island and over half its accessible forest, had been cleared. Our second fact is implied by the first. Once the island's sugar complex had collapsed definitively, in the 1530's, Madeira *did* experience "great want" when it came to timber. It was no accident that even timber for the casks of Madeira's famed wine was shipped from New England in later centuries (Duncan, 1972: 124, 153–55; Lyall, 1827: 361).

If the modern conquest of the Atlantic was destined to be a grand affair, it began with a few modest steps. When the Portuguese occupied Madeira, a small island 740 kilometers square, in the 1420's, there was little intimation of what was to come. First timber, then grain, would flow from this Atlantic outpost toward

a metropolitan Portugal desperately short of both. It was an essentially medieval relation, perhaps not so different from Rome's tributary exactions a thousand years earlier. By the 1450's, this had changed. As Europe emerged from the socio-ecological crises of the "long" fourteenth century (Moore, 2003a; 2007: ch. 1), commodity production, long-distance trade, technological innovation, and colonial expansion revived, all in ways that looked increasingly different from medieval antecedents. As never before, the commodity form moved to center stage.

Nowhere was this "new look" more apparent than on the island of Madeira after 1450. Exporting relatively little in 1452, Madeira emerged as Europe's leading producer by the 1490's, displacing Sicily, and above all, Cyprus. Developing within the protective carapace of Portugal's "monarchical capitalism" (Dias, 1967), Madeira's sugar boom was cosmopolitan from its inception: Genoese and Flemish capitalists sustained the commerce (and soon, the production) of sugar, Portuguese settlers planted cane and drew timber from the hills, Canarian, and later African, slaves carved irrigation channels from the mountainsides, then carried out the grueling labor of planting and cutting cane.

This first sugar revolution was an audacious act of biophysical transformation. Madeira's sylvan landscape quickly gave way to savannas, its ashes feeding the soil, its trees fueling the great boilers that turned cane juice into crystal sugar. Such conquest was, in successive turns, self-sustaining and self-defeating, the source of the island's boom, and in time, the pivot of its collapse. More than 10,000 hectares were planted in sugar at the dawn of the sixteenth century, and for a few years, more than 500 hectares of forest were picked clean to feed the sugarmills, *every year.*

Medieval sugar producers had taken a toll on the forests of the Mediterranean (Lombard, 1959). But it was never like this. In medieval Europe, deforestation was measured in centuries; after 1450, in decades. From the Saxon Erzgebirge, with its silver and copper mines, to the timber districts of Stavanger, to the cereal zones on the banks of the Vistula, early modern capitalism practiced serialized deforestation (Moore, 2007a; 2010a; 2010b; Williams, 2003)—half-century booms in which commodity production surged and the forest retreated were the norm, followed by the inevitable crash. Madeira's sugar revolution—along with central Europe's metallurgical boom—would establish this pattern.

Booming by the 1470's (nurturing, incidentally, a young Cristobal Colon), Madeira's sugar economy had collapsed by the 1520's. In 1472, the island exported 280 tons, peaking at nearly 2,500 tons in 1506. By 1530, output had fallen nearly 90%, very close to its 1472 output. Madeira was not, in the main, outcompeted. Although its decline may have been reinforced by the subsequent emergence of new competitors, Madeira's sugar complex had already collapsed. Nor was this collapse the expression of a glutted market. Rather, it appears that Madeira's sugar complex collapsed under the weight of its socio-ecological contradictions, above all the exhaustion of the forests from which flowed the extraordinary fuel supplies demanded by the mills. New production centers would soon come to the fore, São Tomé by the 1540's, Pernambuco by the 1570's, Bahia in the 1620's, Barbados by the 1670's, and thence Jamaica and St. Domingue over the course of the eighteenth century (see table 1).

Table 1

The Sugar Commodity Frontier, 1450–1800

Region	World Primacy
Cyprus	1350's–1470's
Madeira	1480's–1520's
São Tomé	1540's–1570's
Pernambuco	1570's–1620's
Bahia	1620's–1670's
Barbados	1670's–1720's
Jamaica & St. Domingue	1720's–1790's/1820's

Sources: Dunn (1972); Galloway (1989); Klein (1999); Maddison (2001); Mauro (1983); Moore (2007); Schwartz (1985); Pereira (1969d); Fraginals (1976); Tomich (1990).

Madeira's spectacular history begins with a deceptively simple act of Crosby's ecological imperialism (1986). Over a decade before Portuguese settlers arrived on an uninhabited Madeira in the 1420's, they put ashore cows, pigs, and sheep—a strategy of "biological invasion" (McNeill, 2003) that would be repeated across the great arc of sugar's Atlantic archipelago. Madeira's biota was

consequently transformed even before human arrival. This was not always to the settlers' advantage. Nearby Porto Santo—which along with Madeira and the Desertas constitutes the Madeira island group—had been the scene of an initial biological invasion a century before. Amongst the Eurasian animals deposited on Porto Santo were rabbits. The latter's renowned fertility and appetite for vegetation set the stage for severe wind and rain erosion by the 1430's—"to such an extent that agriculture on the island suffered seriously" (Goodfriend et al, 1994: 311). Shades of nineteenth century Australia, to be sure (Ponting, 1991: 171)!

Madeira's heavy forest cover protected the island from a similar fate. Even today, in the mountains that transect the island east to west, there survive between 15,000 and 22,000 hectares of the original laurisilva forest. The forest remains so dense that it is "almost impenetrable," except for the irrigation canals know as *levadas*, and a few paths no more than 1-2 meters wide (UNESCO, 2000: 93, 96 [quotation]; n.a., 1999).

How much difference a century would make. By the time of Camões' visit in the 1560's, the once-bountiful forests below 300 meters had been cleared. Madeira had, in the intervening century, moved from sugar to wine. It was a shift from a fuel-maximizing, to a fuel-minimizing, cash crop—not, as we shall see, by accident.[3]

The rise of sugar and the fate of the forest were closely connected at multiple turns. There were three basic requirements for sugar production in this era. There had to be labor power to cultivate and then process the cane. There had to be fuel for the boilers that cooked the cane juice. And there had to be plentiful land to ensure soil fertility, and to ensure a profitable scale efficiency, since cane milling and initial processing required heavy capital outlays.

The clearance of the land came first. Between the 1430's and the 1450's, Madeira's economy pivoted on cereals and timber. Indeed the two were of a piece. Timbering made room for cereals, and peasant cultivators found by-employment in the timber trade. Indeed, here as in so many cases, the timber frontier arrived first. São Tomé and Brazil would also begin as timber colonies (Dean, 1995; Lebigre, 2003).

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[3] With a different sequence of crops, Genoa (from which sprang the capital that powered Madeira's sugar revolution) had done much the same in its hinterland during the fifteenth century in response to serious deforestation (Lopez, 1964: 454).

The forests were not merely burned away. Timber was an important cash crop in its own right. Madeira's forests supplied the raw materials for construction, furniture, cases, and barrels for the sugar trade, and for shipbuilding, among other uses. So long as accessible forests remained abundant on Madeira, as they did through much of the fifteenth century, cheap timber drove down the costs of production on the island, and in Portugal's leading cities. Cheap construction timber meant lower costs for building warehouses, docks, and all manner of basic infrastructure in an imperial economy that drew its lifeblood from seaborne trade. Lower costs in turn enhanced Madeira's competitive position in the world sugar market, and Portugal's competitive position in the struggle for commercial hegemony in the Indian Ocean.

Madeira's timber alleviated *aggregate* pressure on Portugal's relatively sparse forests at a time when the opportunities (and imperatives) for colonial expansion were greatest (Boxer, 1969). So great were Madeira's timber exports, that the chronicler Azurara[4] reported in 1446 on its connection with a new architectural style (1453b: 300). There began to appear in Lisbon "lofty houses towering to the sky, which have been and are being built with wood from" Madeira (Azurara, 1453a: 9). So plentiful was the timber, especially its prized cedars and red yews—trees that were subsequently wiped off the face of the island (Mason, 1850)—that Cadamosto reports new styles of furniture manufactured from these valued trees (1455: 9).

We will return to the forests momentarily. It is clear that Portugal, on its own, lacked sufficient timber for its overseas ambitions (Devy-Vareta, 1985; 1986). It is equally clear that Madeira was the first major step forward in the Empire's ecological fix strategy, aimed at resolving the sylvan inadequacies of the metropolis. This would be a long march of many steps. The colonization of Madeira, from this standpoint, surely killed no less than two birds with one stone. The establishment of the island as a cereal and timber colony went hand-in-hand. Indeed, these were complementary activities.[5]

For Portugal was short of bread and not just timber (Braudel, 1972: 196–97; Malowist, 1964; Serrão, 1954). Hungry Portugal de-

[4] Gomes Eannes de Azurara (1410–74), the Crown's chief archivist from 1454.

[5] In mid-sixteenth-century Brazil, the *engenhos* during slack periods (of which there were many more in cereal than in sugar cultivation) would set the slaves to work collecting brazilwood (Mauro, 1983).

manded cereals, and the sooner the better. Settlers were shipping wheat to Lisbon by the 1430's, and more than half the harvest was exported by mid-century (Serrão, 1954; Moran, 1982: 64). By mid-century, "in the western part of the island, standing in the farm of João Gonçalves . . . the harvests [of wheat and vines] stretched as far as the eye could see" (Serrão, 1954: 339). The ash from the burned forest was worked into the soil and provided an important, albeit ephemeral, source of fertility. Once these nutrients were absorbed, yields declined, and there was renewed pressure to carve out fresh land from the forest. Cadamosto in 1455 observed that cereal agriculture, which "at first [in the 1430's] yielded a return of sixty and seventy for one, . . . at the moment . . . has declined to thirty or forty for one, *because the land is being daily exhausted*" (1455: 9, emphasis added; also Astley, 1745: 560).

This cereal-timber frontier set the stage for the sugar revolution of the 1450's in two major respects. First, in establishing a modest demographic basis for the island—there were, Cadamosto reports (1455), 800 residents in the 1450's—the cereal-timber frontier developed a smallholder society capable of growing sugar, although not without foreign capital, as we shall see. Secondly, the cereal-timber frontier coordinated the construction of the island's irrigation infrastructure. Sugar is a thirsty crop, and although the southern part of the island enjoys a mildly warm and humid climate, it would be a stretch to call it tropical. Madeira is not São Tomé or northeastern Brazil, and in contrast to these later frontiers, its sugar revolution required a significant hydraulic infrastructure. Madeira's mountainous topography is such that freshwater sufficient for large-scale agriculture could be wrested from the island only with great effort. The first irrigation canals, called *levadas*, were built in the 1430's and 1440's. From the southern half of the island, the topography rises such that one reaches an elevation of nearly 900 meters in just five kilometers, and another 1800 meters over the next 10 kilometers (see map in Greenfield, 1977: 538). It was this "unlikely relief of the island" that made the *levadas* a "gigantic undertaking" (Lamas, 1956: 104, quoted in Greenfield, 1977: 541). Today the *levadas* remain the island's most distinctive geographical feature, extending 2100 kilometers on an island that runs just 50 kilometers east-to-west and covers 741 km^2 (Reynolds, 1997).

It is possible that burning and timbering reduced forest cover enough to alter the island's hydrology (Grove, 1995: 29; 2002: 51). In the fifteenth century, the Socorridos River was deep enough to float timber to the shoreline, and also to power the most productive sugarmills. By the nineteenth century, it was but a "mere stream" (Mason, 1850: 162; Brown, 1901: 133; Scherzer, 1861: 64; Vieira, 1993: 6).

More certain is that rising agricultural output and growing population–augmented by Portuguese voyages to the Canaries and to West Africa–required more and more water. The ensuing construction of the *levadas* was as global as it was transformative. Technical expertise and financing were supplied by the Genoese; Portugal provided settlers, and slaves–at first Canarian and then African–performed most of the labor. The Canarians had been dragooned by successive Portuguese invasions–there were four major expeditions alongside "numerous trips" to the Canaries between 1424 and 1446 (Vieira, 1996; Mercer, 1980: 225–27).[6] Set to work building the *levadas*, the slaves were lowered and then suspended by ropes "over the mountain precipices" to carve the watercourses "out of the solid face of the rock" (Ramsey, 1920). This was dangerous work. Building *levadas* consumed human nature at a ferocious pace. "The water had to be diverted, almost always at distant points of difficult access. The task therefore *was not only exhausting but dangerous, taking many lives and was not completed for many years*" (Lamas, 1956: 104, emphasis added, quoted in Greenfield, 1977: 541). Hundreds "perished by crashing onto the rocks below" (Ramsey, 1920; also Crosby, 1986: 78; Watson, 1983: 103).

Wheat would be displaced by sugar in the 1450's. "This isle is very scarce of oile and of corne," Africanus reported in the 1520's (1600: 56). The very rapidity of this transition from grain to sugar cannot, however, be explained by market forces alone; it must be viewed in terms of the broader ensemble of Portuguese imperialism as ecological project. Sugar, it is true, was more profitable than wheat at the onset of the mid-fifteenth century expansion; but its profitability *for Madeira* and within the Portuguese Empire was conditioned on a broader geographical reconfiguration. Madeira's cereal cultivation was not simply displaced by an abstract Smithian logic. Wheat was displaced *because* it could be relocated

[6] "From the middle of the fifteenth century, the references to Canarian slaves in Madeira as shepherds and mill workers are frequent" (Vieira, 1996).

to the Azores, which became "the granary of Lisbon and Madeira" (Mauro, 1983: 206; Serrão, 1954).[7] The transition to sugar depended also on cheap labor, drawn initially from the Canary Islands and thence West Africa (Vieira, 1996; Mercer, 1980). All of which is to say that the restructuring of Madeira's political ecology was dialectically bound to the geographical expansion of the "vast but weak" capitalist world-ecology, and therefore to broader shifts in its division of labor. These movements of expansion and restructuring were decisive in establishing the conditions for the island's sugar revolution.

CLASS/CAPITAL/PROPERTY IN THE "VAST BUT WEAK" CAPITALIST WORLD-ECOLOGY: THE CONDITIONS OF MADEIRA'S SUGAR REVOLUTION

Madeira's sugar revolution is usually dated from 1452, when Henry the Navigator gave his blessing to what is sometimes characterized as the island's first sugar mill. It was surely not the *first* mill. It was probably the first water-powered sugar mill, which would dramatically increase capacity, since we know that the island was producing 6,000 arrobas (84 tons) of sugar by 1454 (Pereira, 1969a: 82).[8] By the 1450's, modernity's first sugar revolution was in the offing. Sugar's ascent was wheat's decline. Sugar "had killed wheat," observes Serrão (1954), who sees the definitive transition from wheat to sugar in the 1470's. "Farmers growing crops [other than sugar] were quickly bankrupted" (Taylor, 2005: 41). Between 1454 and 1472, sugar production increased by over 230%, to 280 tons; by 1506, it expanded another 785%, to 2,480 tons (calculated from Schwartz, 1985; Pereira, 1969b: 454).

By the end of the fifteenth century, Madeira had displaced Cyprus from the commanding heights of the European sugar economy. Atlantic sugar was found everywhere from Antwerp to Augsburg to Istanbul (Galloway, 1977: 190–91). So great was this small island's revolution that it "cause[d] the distribution of sugar [to flow] more freely over the whole of European than had ever happened when the Mediterranean was the only supplier" (Deerr, 1949: 100).

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[7] This led, we might add, to the deforestation of several of the Azores in the seventeenth century (Tutin, 1953: 55).

[8] The Portuguese medieval *arroba*, in use until 1504, was 28 lbs. (Pereira, 1969a).

By 1530, however, sugar output had fallen to the production levels of the 1470's, a 90% decline. The decline after the 1506 peak was slow and steady for a few years. But at some point in the next decade, the sugar complex's underlying contradictions compelled a more dramatic contraction of output. Even in the face of rising world market prices for Madeira's sugar (O'Rourke & Williamson, 2002: 446–48), and no major competitors for the island's high-quality sugars (even after the rise of São Tomé in the 1540's), production continued its downward spiral. "If in 1547... the economy of the island was still based on bimodal structure of sugar/wine," by 1575 Vieira sees "the *total abandonment* of sugar cane" in favor of wines (1993: 10, emphasis added). An overstatement, to be sure (see Mauro, 1983), but it is one that highlights the essential movements.

What had happened? The fuel requirements of sugar were matched only by metallurgy in early capitalism (see Moore, 2007). And so the short answer is that sugar devoured the forests, and therefore the very conditions of Madeira's ascent also explain its rapid decline. But the short answer is easily misunderstood. The problem was not a scarcity of resources that eventually imposed an *exogenous* "natural limit" on Madeira's sugar revolution. Rather, the evisceration of the island's forests was the *historical* condition of success *and* crisis, actively produced in and through the emergent capitalist order of the first sixteenth century. The accumulation of capital won in Madeira through the phenomenal forms of environmental degradation, such as deforestation, enabled the world-historical advance of the sugar commodity frontier, next to São Tomé and Brazil.

There are two competing explanations for Madeira's decline. In the first place, historians of sugar and slavery attribute Madeira's decline from sugar primacy to competition from Brazil and São Tomé, even from the Canary Islands (e.g., Galloway, 1989; Klein, 1999: 14). It is an explanation that dates to the nineteenth century (White, 1851: 53). But there's a problem with the Smithian explanation. The timing just isn't right. Madeira's "rapid decline" spans 1516–37 (Albuquerque & Vieira, 1988: 29). By the 1530's production declined to a level not seen since the 1470's (Vieira, 2004: 48; also Deer, 1949, I: 101). In 1529, São Tomé was producing not more than 80 tons of sugar, and rather poor quality sugar at that. Brazil's sugar exports were modest until mid-century.

Historians of Madeira have offered a more compelling explanation of sugar's decline after 1506, one that weaves together world market forces and agro-ecological problems, labor scarcity, and even the impact of climate change on the island (Pereira, 1969a; 1969b; 1969c; 1969d; Vieira, 1993; 2004; 2009; Albuquerque & Vieira, 1996). This is a more compelling point of departure, and I will return to these socio-physical factors in accounting for the crisis of the sugar regime in Part II. Missing in these explanations is the devastation of the forests as cause and consequence of Madeira's rise and fall. While soil exhaustion stands as sugar's most commonly cited biophysical problem (e.g., Mintz, 1959; Castro, 1966), the exhaustion of forest resources–reinforcing and amplifying a broader repertoire of socio-ecological pressures inscribed in the sugar frontier–is the most likely pivot of production *collapse*. In the absence of catastrophic erosion, capitalist agriculture has proven adept in managing soil fertility. The management of forest resources, however, posed much tougher challenges.

This argument for forest crisis as constitutive of the rise and demise of Madeira's sugar complex is built out in two steps. In the rest of this section, I trace the ways that class, capital, and property mixed with the transformation of landscape to produce favorable conditions for the sugar revolution, even as signs of trouble became evident. Next, I demonstrate the plausibility of energy crisis as the pivotal factor in Madeira's decline.

Madeira in Monarchical Capitalism: How Monarchical? How Capitalist?

Cyprus produced 800 metric tons of sugar at its peak in 1450, but less than half as much in 1500, a decline that owed much to deforestation (Ouerfelli, 2008: 130). Madeira's production, meanwhile, soared to more than six times its Cypriot competitors (Maddison, 2001: 60–61; Blackburn, 1997: 109). It was a changing of the guard, and not for the first time. Cyprus, home to the precocious agro-capitalism of Venetian merchant-planters a century earlier, could show, but not *lead*, the way (Solow, 1987: 714–15; Verlinden, 1970: 19–20). The signals of decline were surely evident to the Genoese, who in any event had been ousted from most of the Levant. It would be Genoese, not Venetian, capitalists who launched the modern sugar frontier, moving it westward to the Algarve in southern Por-

tugal, and thence into the Atlantic. By the 1490's, even Venice was drawing more sugar from Madeira than from established suppliers in Sicily, Cyprus, and Egypt; in the process Venice saw its lucrative trade with the English slip away (Giustiniani, 1519: 110–11).

Sugar inaugurated a revolutionary transformation of Madeira. Nevertheless, a key question remains. In what sense, or to what degree, was this a *capitalist* revolution? There are really two major ways to approach the question. The first is to sketch the connections from the standpoint of the emerging world division of labor. This is Wallerstein's approach (1974). Brenner calls this optic "ultra-Smithian" (1977), but it is by no means clear that viewing the world division of labor from the standpoint of world-economy is any more or less illuminating than viewing it from the standpoint of the production unit or region. It *is* certainly the case that the scalar vantage point—world-economy? point of production?—brings distinctive processes into view. Is there a way to weave the two scales together in a manner that moves beyond the banal invocation of a local-global dialectic? How might we take to heart the spirit, if not the letter, of Brenner's argument for the centrality of social property relations as the pivot of modern economic development, and weave this together with Wallerstein's persuasive contention that the rise of capitalism was part and parcel of an epochal reshaping of "world ecology" (1974: 44)?

Let me begin by stating my position simply. On Madeira in the "first" sixteenth century we find an island that was *becoming capitalist* even as it bore some resemblance to the socio-ecological organization of the medieval Mediterranean. It was becoming capitalist for three reasons. First, as we have seen, there was a secular trend toward rising commodity output. This was true not just in nominal terms, but also relative to the island, and to the Portuguese empire. Secondly, from the "first" to the "second" sixteenth century, there was no de-commodification, even as Madeira's sugar economy entered a protracted crisis in the 1520's. The island would quickly restructure around wine (Duncan, 1972: ch. 3). As early as 1560, Nicholas reported that Madeira, while producing some fine sugar, was "chiefly famous for its good wines" (1583: 557). Finally, the Madeiras were a crucial outpost in the construction of Portugal's global empire, one that had become "fully committed to commercial expansion" by the end of the fifteenth century (Greenfield, 1979: 116; also Malowist, 1964).

Madeira may not have been home to productivity-maximizing capitalist farmers akin to those of sixteenth- and seventeenth-century England and the Low Countries. But then, Madeira was a colonial zone, and heroic yeomen rarely populated colonial zones. The colonies of early capitalism were, however, in great measure the creation of plantations, and the Atlantic islands were testing grounds for this gruesome apparatus of territorial domination and commodity production. The word plantation conjures images of the great planters of seventeenth-century Brazil, or the cotton aristocracy of the antebellum American South. For this reason Galloway (1989), among others (Vieira, 2004), object to its application to Madeira. They rightly argue that production was small-scale, compared to later developments. But this is, after all, the point. The essential features of the model were in place: 1) the estate's dependence on finance and merchant capital, operating on a world-scale; 2) the slave form of production; and 3) its tendency to mine the soil and exhaust other forms of biophysical wealth, not least the laborers.

While medieval Cypriot sugar production was organized juridically as demesne land, among other things allowing European seigneurs to levy corvées from the local peasantry (Greenfield, 1979: 92), Madeira's colonization proceeded on a much different basis. The Portuguese Crown gave Madeira to Henry the Navigator as a colonial fief in 1433. But if this was feudalism, it was an exceedingly unusual form. For beginners, there was no parcellization of sovereignty. The Crown's courts retained the right to decide civil and higher criminal cases. The Crown retained its right to levy taxes (Verlinden, 1970: 207–08).

Perhaps most fundamental was the property system. The basic land grant unit on Madeira was the *sesmaria*, the size of which varied according to geographical conditions (Albuquerque & Vieira, 1988). "The law compelled landowners to cultivate their land under penalty of expropriation" (Verlinden, 1970: 219). Promulgated in 1375 on the eve of the Aviz Revolution (1385), the *sesmaria* was not so much a feudal social form as it was a specific socio-ecological response to feudal crisis. The fourteenth century witnessed an unprecedented concentration of landholding within Portugal, especially in the hands of the religious Orders (Marques, 1972: 112–13; Anderson, 1974: 172; Castro, 1970: 135–38). The *sesmaria* was a mechanism through which the Crown could promote (desperately-

needed) cereal cultivation on lands that were either unused or that had been converted to stockraising (Verlinden, 1970: 219). From this standpoint, the *sesmaria* appears as an assault waged by a precocious absolutist regime on parcellized sovereignty rather than a continuation of the latter.

On Madeira, *sesmarias* were given to settlers as land grants that could be held in perpetuity, "*provided that it was in cultivation within five years of receipt*. If cultivated, the land could be sold, given, and/ or inherited as private property" (Greenfield, 1979: 99, emphasis added). Originally, the specific time frame was a decade. In 1433, it was changed to five years, in the 1440's to three, then to even shorter periods as the century wore on (Vieira, 2004: 50–51; Verlinden, 1970: 214). These measures created the basis for a land market, and consequently, for the emergence of a competitive property system that meted out dispossession as a penalty for poor performance. Indeed, once cultivated for the specified period, "the lord could not prevent the colonists from selling their lands and settling elsewhere" (Verlinden, 1970: 209). Of special import was Henry the Navigator's surficially feudal, yet powerfully commercializing, role in establishing the island's first major sugar mill in 1452. Henry reached an agreement with his "escuidero" (squire)—a certain Diogo de Teyve—to build this mill, a relation through which the prince would receive one-third of the produce. This was no lord-vassal relation. It was, rather, a contractual one: "The prince [Henry] himself called the agreement a *contract*" (Verlinden, 1970: 216, emphasis added). Crucially, Teyve could be dispossessed if he failed:

> [S]ugar producers *had* to allow mills and presses to work at full output. . . . If Teyve was successful he would enjoy a monopoly; if not, the Infante [Henry] could grant another contractor the right to construct a mill. . . . This contract had no trace of feudal or demesnial form. It started a sort of partnership between the Infante and his squire for the production of sugar on Madeira. . . . [This] was *the original deed of birth of sugar production on the island* (Verlinden, 1970: 217, emphases added).

Henry may not have been a capitalist entrepreneur, but he was certainly a territorial one who drank deeply from the well of Portuguese "state capitalism." The insistence on maximizing produc-

tion, coupled with a legal framework allowing land to be treated as a commodity and the Crown's increasingly accommodating attitude toward *resident* foreign merchants, explains something of Genoese capital's movement into production on the island during the 1480's. Genoese capital, and technical expertise from experience growing sugar in the Algarve,[9] had been present from the beginning (Fernandez-Armesto, 1982: 199). In 1455 the greatest sugar planter on the island was a Genovese. The last two decades of the century witnessed "at least six aristocratic Genoese families acquire extensive sugar plantations" on the island (Coles, 1957: 19; also Bovill, 1928: 22). By the early sixteenth century, fully two-thirds of the island's canefields were in the hands of "foreigners, especially Genoese and Florentines, or... New Christians" (Blackburn, 1997: 109; but see Rau, 1964).

It was this confluence of global capital, the *sesmarias*, and the expanding sugar market that created "the basis for social differentiation among the first colonists and opened the door to the growth of large-scale properties" (Vieira, 2004: 51). We needn't overstate the case. But neither should we understate it. The Crown proclaimed in 1496 that neither land, nor slaves, nor equipment could be seized for debts (Vieira, 2004: 59). But then, by this point a transition from independent proprietors to tenant farming was well underway (Albuquerque & Vieira, 1998: 24). The diffusion of tenancy, foreshadowing Brazil's sugar regime (Schwartz, 1973), meant that dispossession of real property was not much of an issue; farmers (as tenants) could be ejected from the land without any dispossession of property. And in any event, as was the case with forest regulation–which always indicated forest scarcity rather than its opposite–such proclamations *against* were just as surely recognitions *of* dispossession. Land, slaves, and equipment *were* being seized for debts on Madeira in the 1490's. Otherwise, there would have been no call for Crown intervention.

The island's economic sociology turned on a threefold division of labor: 1) merchant capital; 2) rich planters who owned *engenhos* (sugar mills); and 3) the majority of cultivators who owned land but not mills, and some who owned neither. (These latter would be called *lavradores da cana* in colonial Brazil.) These were over-

[9] Although it was certainly not just the Genoese. Many of Portugal's migrants to Madeira came from the Algarve.

lapping and fluid categories.[10] Merchants owned mills. Successful cultivators became millowners. The vast majority were cultivators, increasingly tenants, who by the end of the fifteenth century owned just a few slaves. Over half owned just one or two, and just 10% of slaveowners held more than ten (Vieira, 2004: 59). In the captaincy of Funchal, the island's capital, there were 14 *engenhos* but 209 cultivators in 1494 (Vieira, 2004: 53). The cultivators were a chronically indebted class. That is to say, they were in a position where they had to sell to survive, risking in the process either dispossession, or the debt-driven surplus squeeze of labor and land:

> Here, *even more than in [sixteenth- and seventeenth-century] Brazil,* there were many proprietors without the financial resources to set up the basic industrial operation of a mill and thus remained dependent on the services of the [*engenhos*].... Direct sales, sometimes pledged before the harvest, were often used to pay existing debts.... *[Here] was a system that tended to subordinate the producers* (Vieira, 2004: 53, 70, emphases added).

No wonder that Koebel refers to the island's class relations in the early sixteenth century as one in which "bitter strife became frequent and general between the two classes," the cultivators and the millowners (1909: 20). Even earlier there were signs of conflict. In 1472, Portuguese cultivators on Madeira protested against Genoese hegemony in the sugar trade, complaining that cane farms "had been destroyed, damaged and lost owing to the presence of the Genoese" (Rau, 1964: 8). By 1494, there was widening inequality within the classes directly engaged in production. In that year, as the sugar boom stratified property holding, the top 4.5% of landowners produced 25% of the island's sugar, whereas the bot-

[10] The categorical overlap can hardly be overstated. "Merchant capital" must be comprehended as an accumulation strategy, one amongst many. Mercantile activities were primary at certain times and places, for certain clusters of business organizations, but the golden rule of capitalism nevertheless prevailed–follow the money, pursue the high-profit lines. Richard Pares' observation about the British West Indies in the seventeenth and eighteenth centuries is therefore scarcely less relevant to the earlier moments of the sugar commodity frontier: "It was characteristic of the fluidity of the economic relations in the sugar colonies at that time that a general merchant should be, at the same time or successively, a partner, a tenant and a landlord of sugar plantations" (1950: 41).

tom 75% produced just 30% (calculated from Galloway, 1989: 52).[11] Among the bottom 88 landholders (of 221), average output was less than 1.5 tons (Galloway, 1989: 53). Undoubtedly aggravating the political situation was the presence of putatively "foreign" planters at the top of the hierarchy. The gulf widened still further in the 1520's, as the sugar sector was gripped by crisis (Vieira, 1995).

Was there a "reproduction squeeze" that led producers to over-exploit the soil? It is clear that the sugar revolution quickly generated a mounting volume of socio-ecological contradictions. At the very moment when the wheat regime definitively gave way to sugar, that is during the 1470's (Mauro, 1983: 206), conflicts escalated over water- and property-rights (Albuquerque & Vieira, 1988). Water and land became scarce as sugar advanced. Although the expansion of the *levadas* made more water available in absolute terms, demand outran supply.

The situation was much the same with land. During the 1470's "the policy of land concession [the *sesmarias*] ran into trouble... [and] the amount of arable land became more restricted" (Albuquerque & Vieira, 1988: 23). The proliferation of cane farms was so rapid that burning forest to create arable land was "recognised *as an ecological hazard and as a threat to the sugar economy*" (Albuquerque & Vieira, 1988: 23, emphasis added). There were escalating conflicts over the practice of burning, which often spread to neighboring cane fields (Vieira, 2004: 53–54). Access to the forest was progressively tightened, first in 1485, when the Crown "prohibited the distribution of uncultivated land in the hills and forests on the north side of the island" (Vieira, 2009: 12). In the next decade, a 1492 ordinance "imposed sanctions on those who dared to cut cedar and barbuzano," high-quality construction timbers (Magalhaes, 2009: 161). Next, firewood cutting was limited to property-owners and their agents (Magalhaes, 2009: 161). Between 1501 and 1508, the Crown ended the distribution of land through *sesmarias* specifically in response to the fuelwood demands of the sugar sector. The goal was to prevent, in Albuquerque and Vieira's words, "the *further* reduction of the forest area so necessary to sugar growing" (1988: 24, emphasis added).

[11] Albuquerque and Vieira provide modestly different figures: "The fifteen planters who made up 6.7 percent of all producers in 1494 produced 20 percent of output" (calculated from Albuquerque & Vieira, 1988: 25).

DEFORESTATION AS THE PRICE OF SUCCESS: A HISTORICAL GEOMETRY

But why should it be so important to prevent the "further reduction of the forest area so necessary to sugar growing," precisely at the apex of the island's sugar boom? The short answer is that sugar consumed the forest at breakneck speed.

On Madeira's sugar output, we have reasonably solid figures (Pereira, 1969a; 1969b; 1969c; 1969d). In table 2, I reconstitute these into five-year, moving averages, and build out two major vectors of forest exploitation: the expansion of cultivation into the forest, and the expansion of fuelwood exploitation. These were two main ways that sugar advanced into the forest. The first was through the expansion of cultivation. Throughout the early modern history of sugar, new arable land was commonly won at the expense of forests, from the Atlantic islands to Brazil and the Caribbean (Moore, 2007). I have reasoned that only 20% of new arable land was subtracted from the forest, presuming that planters took advantage of our second vector of deforestation. This latter was through direct exploitation, to satisfy the construction and, above all, energy demands of the sugarmills. Demand for fuelwood was by far the greatest driver of forest clearance.

Madeira spans 741 km^2, of which about 60% (445 km^2) was covered with dense *laurisilva* forests prior to colonization, along with cedars and red yew (European Environment Agency, 2002). Much of this forest was inaccessible. The island's dramatic vertical topography meant that between one-quarter and one-third of this forest was inaccessible to settlers in the "first" sixteenth century. Today, 150 km^2 of old-growth *laurisilva* survives, draping the mountains of the island's northern half (UNESCO, 2000: 93; Weijden & Pacheco, 2003).[12] How much of the original forest could be exploited by the settlers of the time? Given the prevailing technology, and the skills demanded to clear forest effectively, I am doubtful that we are looking at more than 300 km^2 available for commercial use. It is one thing for a peasant to cut fuelwood for the home, quite another to feed the maw of a sugar complex disciplined by the world market.

[12] This "main forest is believed never to have been felled or cut and includes some massive old trees . . . over 800 years old" (UNESCO, 2000: 94).

Table 2
Sugar and the Fate of the Forest, Madeira, 1445–1509
(Five-Year Averages, in Hectares)

	Canefields (from forest)	Sugar Production	Deforestation for Fuelwood	Cumulative Deforestation
1445–49	200	40	67	
1450–54	300	60	100	
1455–59	450	90	150	
1460–64	600	120	200	
1465–69	900	180	300	
1470–74	1,350	270	450	
1475–79	2,025	405	676	
1480–84	3,050	610	1,016	
1485–89	4,000	800	1,333	
1490–94	5,000	1,000	1,667	
1495–99	6,000	1,200	2,000	
1500–04	7,500	1,500	2,500	
1505–09	9,500	1,900	3,167	
Total	10,500* (1,900) ha	N.A.	13,626 ha	15,526 ha

*Includes an additional 1,000 hectares to compensate for declining land productivity.

Sources: Cadamosto (1455); Pereira (1969a; 1969b; 1969c; 1969d); Miller (1994); Moore (2007: chs. 5, 6); Rau (1964).

Early modern deforestation is one of those problems easy to assert and difficult to prove. Castro concludes that sugar pushed the island's forests toward "total degradation," leading to a "collapse" in production by the 1530's (2002: 105; also Carita, 2006). It sounds good. But is it *true*? Like the debate over American silver and the rise of capitalism, the question of the relation between forests, energy, and capitalist development has sustained research and debate for nearly a century (see, *inter alia*, Allen, 2003; Flinn, 1958; 1959; Cipolla, 1976; Clow & Clow, 1957; Hammersley, 1973;

Malanima, 2006; Moore, 2007; 2010a; 2010b; Nef, 1932; 1950; 1964; Sombart, 1921, II, ii: 1145–48; Thomas, 1986; Warde, 2003; 2006; Westoby, 1989; Wilkinson, 1973; Williams, 2003). Given the long-standing interest in the "forest-energy question," it is therefore surprising that so little attention has been given over to the key technical questions of forest exploitation, potential energy yield, the fuel consumption of energy-intensive manufactures such as sugar, and technical innovations that set the "limits of the possible."

How can we *know* the extent of forest clearance and its effects? In this section, I focus on a set of quantitative extrapolations based on sugar production figures, fuel consumption, forest yield, and agricultural productivity. My aim is to establish the plausibility of the interpretation. If handled delicately, the *geometrical* representations of environmental transformation that emerge from these extrapolations can serve as useful heuristic guides for the explanation of changing environments (at multiple scales) and economic development broadly conceived. Such historical geometries are crucial to the construction of historical *geographies* of the early modern world, and its commodity frontiers above all. In the next installment of this essay (Part II), I will take this historical geometry to explore Madeira's deforestation and its implications for sugar's decline and their impact on the Portuguese Empire and the emergent capitalist Atlantic.

Agricultural Productivity and the Forest

Because sugar monocultures tended to exhaust soil fertility, throughout the early modern era there was a strong frontier movement, not only across the Atlantic world, but also within the sugar zones themselves. This emphatically modern frontier movement brought together the triple commodification of land, labor power, and sugar in the formation of sugar booms. In Part II, I will take up the pivotal question of declining *labor* productivity in agriculture. For the moment, let us focus on the relation of arable land and forest clearance–sugar and land. This of course is an age-old relation, and the rise and demise of feudal Europe can be read through the advance of arable land and the retreat of the forest (Moore, 2003b; Williams, 2003).

Three distinctive features of Madeira's "first" sixteenth century provide an arresting contrast with feudal Europe. First, the

emergent disciplines of capital led to an acceleration of biophysical exploitation, manifesting an accelerated cycle of planting, exhaustion, and the search for new arable land, frequently carved out of the forest. There was a "metabolic rift" immanent to the earliest moments of the transition to capitalism, as nutrients were removed from the soil and shipped to distant urban markets (Foster, 2000; Moore, 2000a). The conversion of forest to arable land provided a crucial means of attenuating the systemic tendency toward nutrient depletion, which explains something of the close link between agro-ecological exhaustion and deforestation in early capitalism (Moore, 2007; Moore, 2010b). Sugar cultivation engrossed some 10,500 hectares by 1509, more than half the island's potential arable land. Of this, 1900 hectares had been claimed from the forest even before fuelwood extraction is brought into the equation.[13]

Secondly, the temporal disciplines of the law of value and its metabolic rift compelled not only an acceleration of nutrient depletion relative to medieval norms, but new landscape disciplines. This meant monoculture above all. As we will consider in more detail in Part II, monoculture was a powerful strategy of increasing labor productivity over the short run, at the same time as it created fertile environments for the very weeds and pests that undercut productivity gains over the middle run. Thirdly, while much of the technological apparatus remained the same, sugar production was now integrated into systemwide financial circuits that unified (however tenuously) production and exchange in northern Europe, Braudel's "global Mediterranean" (1972), and an expansive if diffuse capitalist Atlantic. The capitalist circuit of accumulation (M-C-M+) increasingly dominated the rules of reproduction for sugar production and trade; sugar's "natural distinctiveness" existed as something to be dissolved into the "abstract generality" of money capital (Marx, 1973: 141).

These three tendencies were magnified further by Madeira's geography. Madeira's potential mass of arable land was exceedingly modest. In contrast to Barbados two centuries later (Dunn, 1972), room for expansion into the interior was limited. Where Barbados is unusually flat, Madeira is essentially a mountain rising up out of the ocean. On the southern coast, cane might climb

[13] Assuming that 20% of new cultivation expanded into the forest, and that forest clearance for fuelwood and construction needs accounted for the remainder. See below for further discussion.

the mountainsides as far as 400 meters, but no farther–and such elevations were typically reached within three kilometers from the shore. Albuquerque and Vieira see a 2.5-kilometer "corridor [of arable land] parallel to the coast" (1988: 23). This corridor varied considerably, shaped by differing microclimates on the northern and southern coastlines, comprising in their view a theoretical maximum of 300 km² (Albuquerque & Vieira, 1988: 23). This is probably too generous. The island stretches 50 kilometers east to west with a steep incline virtually everywhere (Calvert, 1979: 45). A maximum of 200 km² of potentially arable land is probably closer to the mark. This was, in any event, the area under cultivation in the mid-twentieth century (Câmara, 2006: 217).[14] And of course, all land was not equally desirable, especially land even a few kilometers distant from rivers or *levadas*, and much of it was covered with forest.

The "work" of the forest in sustaining agricultural productivity merits some explanation. For all the attention given over to the "Columbian Exchange" and the biological invasions of the European expansion (Crosby, 1972; 1985; McNeill, 2003), the tremendous windfalls enjoyed by the cultivators of new crops such as sugar is often missed. These windfalls constituted, in Dark and Gent's nicely turned phrase, "yield honeymoons" (2001). Exogenous crops enjoyed a "honeymoon" of high yields–above and beyond the fertility bonus of uncultivated soil. If new settlers could clear forest rapidly, a new wrinkle emerges. New arable land cleared from forest would have "few weeds [and few sources of fungal pathogens] at first, as potential seed sources would have been few, while the landscape remained predominantly wooded" (Dark & Gent, 2001: 73). We may recall Cadamosto's report of wheat yields of 70:1 (1455: 9). While probably inaccurate, it is also probable that the report contained a kernel of truth. Far from exceptional, we have reports of extraordinary yield windfalls throughout the Americas in the colonial era (Super, 1988).

Recurrent yield honeymoons, under conditions of export monoculture (highly favorable to pests, weed, and diseases), accelerated nutrient uptake from the soil and accelerated the evolu-

[14] "No minute piece [of land] seems to be wasted, and many an odd corner and neglected patch which, from its steepness or the poor quality of its soil, escaped cultivation in years gone by, ... has [recently] been ... pressed into service" (Du Cane & Du Cane, 1909: 97).

tion of weeds and pests. Weeds were an especially big problem; they evolved quickly and proliferated even more rapidly. Weeding sucked up huge amounts of labor once the honeymoon was over. A Brazilian source from 1753 identifies weeding as labor-intensive as planting, and an activity that required as much labor as the cutting and carting of cane *combined* (Schwartz, 1985: 142; also Watts, 1985; Peng, 1984; for Madeira, see Mauro, 1983: 206). It is entirely possible that the nutrient demands weed populations created through sugar monocultures greatly outweighed those of the cane itself. Weeds and weeding may have proved a much more formidable barrier to maintaining and improving labor productivity in agriculture than commonly recognized. To the extent that cultivators are unwilling or unable to withdraw from the world market—and indebtedness enforced by the state would play an enduring role in the history of sugar—there would be mounting pressure to find new land upon which to enjoyed a second (and third and fourth . . .) honeymoon.

What was land productivity during Madeira's sugar boom? Two big questions immediately present themselves. First, how much would a hectare, planted in cane, yield? Secondly, how much sugar could be extracted from a given mass of raw cane? A higher extraction rate in the post-harvest processing phase could make good any difficulties in cultivation.

We begin with the passage from cane to sugar. The ecology of sugarcane mandates processing within 48 hours—the sooner the better. Raw cane could not be shipped off the island. There were of course many grades of sugar, and semi-refined sugar was commonly exported for additional processing to Lisbon, Antwerp, and Genoa. The crucial point concerns the rate of extraction, the amount of (semi)processed sugar that was produced from raw cane. My bias here favors a highly efficient rate, which underestimates deforestation.[15]

There is no systematic study of the relation between technology and the rate of extraction in the early modern sugar complex. Making sugar was treacherous work, and every improvement in the rate of extraction was won from decades, even centuries, of experimentation (Galloway, 1989). On Barbados, the rate of ex-

[15] The manufacture of high quality sugars, such as that used in pastries, would result in substantially more bulk reduction, by as much as one-third, and therefore a lower (less efficient) rate of extraction (Vieira, 2004).

traction reached 3.1% in the 1840's (calculated from Simmonds, 1854: 138). By the later nineteenth century, extraction rates varied between 4 to 5.5% (Eisenberg, 1974: 126; McCook, 2002: 80). In Cuba, the higher figure was obtained by deploying steam power and a three-roller mill, neither of which could be found on Madeira in the "first" sixteenth century. Even in the twentieth century, extraction rates rarely hit double-digits; Louisiana's was just 8.6% in the 1950's (Humbert, 1968).

What was Madeira's extraction rate in the "first" sixteenth century? We can begin with the prevailing technology. Warren Dean thinks a 3% extraction rate was standard in late seventeenth century Brazil, although this seems optimistic. The level of efficiency realized by the Brazilian *engenhos* was achieved by the vertical three-roller mill, an important technological innovation introduced during the 1610's (Barros de Castro, 1980). For our purposes, we can observe that the three-roller mill was two major steps ahead of Madeira in the fifteenth century. The conventional narrative places the two-roller mills on Madeira, from the 1450's. John and Christian Daniels (1988), however, find no evidence for two-roller mills on Madeira before the 1520's. Even then, these were horizontal rather than vertical mills—and therefore susceptible to the re-absorption of cane juice into the *bagasse*—and were uncommon until mid-century (Daniels & Daniels, 1988: 514). It is unlikely that the two-roller mills exceeded a 2% extraction rate.

But if two-roller sugar mills did not appear on Madeira until the 1520's, what was the prevailing technology at the dawn of the island's sugar boom? On Madeira in the 1450's, the cutting edge of sugar mill technology was the "edge runner," a mill common to the medieval Mediterranean (Daniels & Daniels, 1988: 514). The edge runner was essentially a large, heavy wheel capable of crushing the raw cane, from which the juice would run into a basin. It could be powered by water or animals. Additional juice would then be extracted in presses similar to those used for olive oil. These had long been used to process sugar in the Mediterranean world. The extraction rate was exceedingly low, in my estimation not more than one percent.

The sugar-to-cane ratio offers a starting point for the historical geometry of sugar's expansion. Our next step is to consider land productivity. The best estimates are from the nineteenth century. Fresh land in Cuba during the 1870's yielded "as much as 119 tons

of cane" per hectare (Eisenberg, 1974: 218). In the same decades, yields in Pernambuco (Brazil) "never exceeded" 60 tons, or annual productivity of 40 tons/hectare (Eisenberg, 1974: 218, 126). Jamaican production in the mid-nineteenth century was 51.6 tons/ha (calculated from Ure, 1853: 758).[16] And 50 tons/hectare was standard for Pernambuco canefields in the seventeenth century (Dean, 1995: 79). Indeed, 50 tons/hectare is the average for Pernambuco today (Porter, Dabat & de Souza, 2001: 833).

What, then, were sugar yields in fifteenth century Madeira? I would begin with Dean's estimate of 50 tons/hectare in seventeenth century Pernambuco. Northeastern Brazil had two great biophysical advantages over Madeira. First, it was warmer and wetter; irrigation was unnecessary. Secondly, Pernambuco's soils, especially the famed *massapé*, were more fertile. The manuring practices common to Madeira's and São Tomé's sugar cycles were unnecessary in Brazil (Dean, 1995: 56). In this light, any estimate of Madeiran sugar yields greater than 40 tons/hectare seems unrealistic.

Land productivity is usually reckoned in annual cycles. But planted cane is not an annual crop. In early modern Brazil and the Caribbean, time to maturity varied between 14 and 18 months. In Madeira and the Canaries, the harvest cycle was closer to two years: "good Soil yields nine Crops in eighteen Years" (Nicholas, 1583: 536; also Landi, 1530: 85). A harvest of 40 tons/ha translates to annual land productivity of 20 tons/ha. Now, replanting was not always necessary. Stalks could be left in the ground to resprout, a process called ratooning. In Brazil and the Caribbean, ratoons matured faster than transplanted cane, taking about twelve months to ripen, but characteristically with a lower yield than cane freshly planted. Thus ratooning, in these estimates, does not alter the land productivity estimates (Schwartz, 1985: 109; Landi, 1530: 85).[17]

From this reading of sugar's history, we can safely estimate that 9500 hectares were planted in cane at the apex of Madeira's sugar boom in 1505–09. But this holds only if we hold constant land

[16] Calculated from Ure's estimate of 7 hogsheads, of 16 cwt each (112 lbs/cwt), for 10 acres (1853: 758), assuming a 3% extraction rate (also Simmonds, 1854).

[17] In the favorable climate and soil of northeastern Brazil in the sixteenth and seventeenth centuries, ratoons were known to give comparable yields for the first and sometimes second ratoon crops (Schwartz, 1985: 109). Not so in sixteenth-century Madeira (Landi, 1530).

productivity, which we know was not constant. (About which, we shall hear more in Part II.) By 1500, the yield honeymoon of the early decades of cash-cropping had passed. We have no reports of the precise *rate* of yield decline for Madeira. Fortunately, these are available for Barbados and Jamaica in the seventeenth and eighteenth centuries. In Barbados between 1649 and 1690, the volume of sugar produced on one acre fell by at least one-third (Barrett, 1979: 22). But the aggregate figure obscures profound unevenness. On those plantations established during the initial boom of the 1640's, yields declined by as much as one-half by 1685 (Watts, 1987: 397). The same thirty-year cycle is discernible for Jamaica. The island's Bybrook plantation, for example, saw output fall from more than 100 hogsheads to just 50 over the last three decades of the seventeenth century. Bybrook, "not yet thirty years under cultivation... was nearly worn out and worth very little" (Dunn, 1972: 219–21). Charles Lesley observed in the 1730's, not more than a half-century after Jamaica's sugar boom commenced, that "Acres of Cane require almost Double the number of Hands they did formerly, while the Land retain'd its natural Vigour" (1740: 337). If a thirty-year cycle of intensive cultivation during the boom years of the 1470's led to a 50% decline in yields, we can tack an additional 1,000 hectares onto our estimate of arable land, for a total of 10,500 hectares of cane planted by 1509.

Sugar and the Forest: Engenhos *of Destruction*

Cultivation's advance into the forest paled next to the sugar frontier's greatest vector of deforestation, fuelwood exploitation. To say sugar is to say deforestation. This was an enduring ecogeographical structure of the modern world-system well into the early twentieth century. (Indeed, as the ethanol revolution gathers steam today, one wonders if the formula ever disappeared.) Once the forests of Madeira, northeastern Brazil, and the Caribbean had been razed, the same pattern was reproduced with the extension of the sugar commodity frontier to Mauritius, Australia, and the Philippines, among other places (Griggs, 2007; Tucker, 2000). At the heart of early modern sugar's ecological vulnerability (*and* its economic dynamism) was the tendency to exploit forests beyond their capacity to renew themselves.

To make one pound of sugar required *no less* than 50 pounds of fuelwood (and this is a conservative estimate). Nearly 700 hectares of forest were sacrificed in 1506 alone to produce that year's bumper crop of 2480 tons of sugar. This was not forest exploitation along the lines of early modern coppicing, such as practiced (unevenly) in England. This was 700 hectares of forest *cut down*. In one year.

Making sugar takes a lot of energy. Its closest counterpart in this era was ironmaking. The estimate that I settled upon for table 2 is a sugar-to-fuelwood ratio of 1:60. This is considerably higher than the two estimates which have gained the widest circulation among environmental historians—Perlin's estimate of 1:46 (1989), and Warren Dean's reckoning of 1:15, in his classic study of the destruction of Brazil's Atlantic forest (1995: 80). The estimates are worth discussing, because the technical details shape our understanding of the enormity of the epochal shift in nature-society relations during the "long" sixteenth century. They are also worth discussing because, as the history of sugar emerges as a crucial site of modern environmental history (Hollander, 2008; Monzote, 2008; Moore, 2007), the quantitative moment of sugar's tendency toward deforestation has not been sufficiently researched. Dean offers no source for his estimate, but Perlin does, and this is worth considering.

Perlin's guesswork has the virtue of drawing upon an eighteenth-century Brazilian source (Couto, c. 1759). Couto's observation of sugar's fuel requirements is phrased in relation to the *pães*, the sugar loaf or "form" that results once the sugar is boiled down and poured into clay pots. The size of these loaves varied. In early colonial Brazil, the standard *pães* was 1–2 arrobas (15–30 kilograms); after the 1660's, this grew to 2–4 arrobas, which became standard in Bahia (Schwartz, 1985: 113). There is, however, a world of difference between two and four arrobas. Two arrobas translates to sugar-to-fuelwood ratio of 1:50; three arrobas, to 1:33; four, to 1:25. The largest mills tended to produce the largest loaves, but these big mills became increasingly *un*representative in the century after 1627. This was a period characterized by the rapid growth of small mills. Output per mill fell by nearly half between 1627 and 1710 (Moore, 2007: ch. 6).

If sugar manufacture demanded so much more fuel than even Perlin suggests, this ought to show up in the evidence drawn from

multiple sites across the early modern sugar archipelago. In eighteenth century Brazil, Lisboa suggested a ratio of one unit of wood for every unit of raw cane, which gives us a sugar-to-fuelwood ratio of 1:100 for an extraction rate that hovered around 1% for sixteenth century Madeira (Lisboa, 1786: 47–50, quoted in Padua, 2000: 269–70). Elsewhere we find very high estimates, although lower than 1:100. If we take the primary source figures provided by Miller (1994) and Schwartz (1985), we find considerable support for the higher estimate. In Bahia during the 1750's (1758), Miller puts the *engenhos'* aggregate fuel consumption at 3,348 m^3 *every day*, or 750,000 cubic meters a year, assuming 224 milling days (1994: 184). If 200 milling days was closer to the mark,[18] then Bahia's annual consumption would come to 669,900 m^3 a year. (If fuelwood harvesting proceeded at a rate of 180 m^3/ha, the rate of effective deforestation was 2977 ha/year.) The nearly 670,000 m^3 of wood translates to 536,657 tons, a figure we can place in dialogue with Schwartz's estimate of 400,000 arrobas (6,525 tons) of sugar produced in Bahia during 1758 (1985: 423). This gives us a ratio of sugar-to-fuelwood of 1:85. If we assume that none of Bahia's mills shut down from lack of fuelwood and therefore a 224-day rather than 200-day year, this brings the ratio down to 1:80 (see also Williams, 2003: 216); but it is doubtful that a 224-day work year was reached on a consistent basis. If 1:60 is a high estimate relative to Perlin and Dean, even higher estimates are not only possible, but probable. Nevertheless, I have opted for a conservative bias that underestimates the likely extent and pace of deforestation.

Sugar's energy demands can now be put into relation with the yield of the forest. This is a socio-ecological question. Even a provisional answer hinges on the biophysical matrix of the forest itself, and the socio-technical regime that takes shape around the latter's exploitation. Yield, in other words, is a historical question that in-

[18] "The adequate construction of reverberatory hearths would solve this problem, ... of the immense quantity of wood wastefully employed[,] ... which causes great losses to farmers and masters of mills, because those who do not possess large forests do not manufacture sugar and those who do have such forests in the future will let their mills go idle on account of lack of firewood, *because this is confirmed by experience*" (Lisboa, 1786: 47–50, order of quotation slightly altered). Even in the absence of serious fuelwood problem, there were many days lost out of the theoretical maximum of 291. In the first half of the seventeenth century, the Engenho Sergipe lost 78 days (only five of them from woodfuel supply problems), bringing the number of production days to 211 (Schwartz, 1985: 101–02).

terweaves the domains of net primary productivity and labor productivity, flows of capital and the contest of classes. How much there was to extract, and how much could be extracted under definite historical conditions. To safeguard against overstating deforestation, I have abstracted other socio-ecological demands on the forest. For instance, the 18,000 people living on Madeira by 1500 (Blackburn, 1997: 109) consumed no less than 18,000 cubic meters of fuelwood each year—about 80 hectares—*just for domestic purposes*! And while forests can regenerate, given time, Madeira's sugar revolution unfolded so rapidly that there was little opportunity to do so.

How much fuelwood could be won from a hectare of Madeira's forest? Here again, the eco-geometric estimates that are the basis for debates on forest crises have often been treated too casually (e.g., Hammersley, 1973).[19] In table 2, I put average yields at 180 tons/225 m^3 of wood per hectare, assuming 1602.2 lbs/m^3 of hardwood.[20] My estimate draws on primary sources and the forestry literature. Our best documentary sources for fuelwood extraction are from nineteenth-century North America, which give us a range of 15–50 cords/acre, or 134–447 m^3/ha for the northern United States (Marsh, 1864: 151; Sargent, 1884: 497, 502, 552, 555, 559; also Whitney, 1994: 145, 213). The middle range estimate of 225 m^3/ha—about 25 cords/acre—fits well with the working estimates among environmental historians (Williams, 2003: 532n; Brannstrom, 2005). It also fits nicely with the forestry literature, which suggests a density—not to be confused with actual yields—closer to 300 m^3/ha for "old growth" temperate forests and

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[19] To this day, Hammersley's essay is widely regarded as the benchmark for discussions of forest crisis in eighteenth-century England (1973). Hammersley's position was that forest regeneration was sufficiently vigorous that any talk of a generalized forest crisis—propelled in great measure by the demands of the country's ironworks—is unwarranted on empirical grounds. The difficulty is that Hammersley relied on precisely one source (Taylor, 1946) as the basis for his estimate of forest regeneration (net primary productivity, in the language of forest ecology). Taylor argued that, under conditions of managed growth, coppiced forest could generate *as much as* 100 cubic feet/acre every year, which translates to nearly 7 m^3/ha. The issue is fourfold. First, Taylor was writing about forestry practices two centuries after the period that Hammersley examines. Secondly, Taylor's estimate was a *maximum* figure. Thirdly, we find multiple sources that find a much lower rate of annual increment—somewhere in the range of 2–3 m^3/ha was the average (see Moore, 2007a: ch. 2; also Fernow, 1911; Lindsay, 1976; Williams, 2003).

[20] Premised on a working assumption of one hardwood standard cord at 5800 lbs. (see Moore, 2007a).

250 m^3/ha for their tropical counterparts (Holland, 1973: 972). Although an imperfect analogue to the hardwoods of fifteenth-century Madeira, old growth Douglas fir stands in the American Pacific Northwest today offer a harvestable potential of 293 m^3/ha (Prudham, 2005: 61). For coastal British Columbia, estimates fall in the same range, 275–325 m^3/ha (British Columbia Ministry of Forests, 2007). European foresters have arrived at a similar ballpark figure, identifying an upper limit of 287 m^3/ha (Nabuurs et al., 2007: 396).[21]

There lies a rather wide gulf, however, between theoretical maximum and attainable yield.[22] For starters, cutting trees was dangerous work (Dean, 1995: 182–83; also Watts, 1987: 185–86; Bridenbaugh & Bridenbaugh, 1972: 42–43, 268–71; Moore, 2007a: ch. 6; Schwartz, 1985: 141). Beyond the inherent dangers of logging, the technology was crude and not all timber was equally suitable for firewood. Large trees on Madeira would have been difficult to fell and then haul. If Madeira's hydrology changed enough during this period to limit river flows (Grove, 1995: 29; Mason, 1850: 162), transporting timber would have become even more costly. Beyond this, there was the labor of chopping the wood into parts small enough to generate sufficient heat; large—and worse, unseasoned—parcels were useless (Antonil, 1711: 202–03; also Miller, 1994; Brannstrom, 2005).

BY WAY OF CONCLUSION: THE CONSEQUENCES OF ASCENT

Even when we deploy a set of cautious estimates, the cumulative geometry of deforestation is huge, amounting to over 15,500 hectares by 1510. Domestic fuelwood demands alone—never mind construction demands—would have added another 800 hectares in

[21] Other European reports indicate a stocking rate of 300–450 m^3/ha for 130-year-old oak and beech outside Vienna (Lewis et al., 2004). These elevated figures occur under highly managed conditions, and should not be regarded as typical.

[22] Extraction from European woodlands, moreover, was significantly lower. Mulhall, looking at late nineteenth-century Europe, suggests 1000 cubic feet per acre of forest "if cut down" rather than coppiced (1899: 297). Using his metric, which puts the weight of one cord (128 cubic feet or 3.62 m^3) at 5000 lbs rather than 5800, this translates to 2,470 cubic feet/ha or 48.24 tons/ha. This contrasts with our much higher figure of 180 tons/ha.

this first decade of the sixteenth century. No wonder that by the early sixteenth century, "the hills surrounding Funchal [the island's capital] were barren" (Vieira, 2009: 12). On an island where labor was costly and labor productivity low, and where sugar's appetite for fuel remained very high, the removal of more than half of Madeira's accessible forest by 1510 represented a major challenge to the sugar regime.

One might well ask if the foregoing historical *geometry* has gone too far? My sense is precisely the opposite, that the geometrical analysis deliberately understates the era's transformations. While the details of Madeira's sugar crisis will be elaborated in Part II of this essay, for now we may conclude with some geographical morsels to complement the cool calculations of our geometry. Amongst these possible morsels, we find successive extinctions of endemic mollusks during the first two centuries of settlement (Goodfriend, Cameron & Cook, 1994). The earliest extinction occurred in the beginning of the sixteenth century (1994: 315–18). The cause?

> Habitat disturbance is mostly likely the cause of most or all of the extinctions. . . . *With the coming of man to the island, there was a rapid and large-scale change in the habitat, from woodland to grassland*, with major effects on both species composition and relative abundances. . . . There was a loss of *most of the woodland species*, presumably mainly as a result of physiological stresses [such as deforestation]. There was also a relative increase in the grassland element (Goodfriend, Cameron & Cook, 1994: 318, emphases added).

Madeira points us towards a new ecohistorical pattern that began to cohere after 1450, at the beginning of Braudel's "first" sixteenth century, and part and parcel of the rise of capitalism not only as world-economy, but as world-*ecology* (Moore, 2003c; 2010a; 2010b; 2010c). It was an unusual pattern indeed, and one that the sugar commodity frontier pioneered in decisive ways. To put it schematically, after 1450 across the spaces of the European economy, production centers were locked in a competitive struggle through which victory was achieved by maximizing and accelerating the extraction of wealth from land and labor. I am not convinced that this early modern ecological revolution was a narrowly Smithian phenomenon, as if the commercializing impulse had been stilled during the fourteenth-century crisis, waiting to burst

its medieval carapace. Such is the perspective articulated by some of our most influential environmental historians (Merchant, 1980; Hughes, 2001; Richards, 2003). Would it perhaps be more fruitful to situate commercialization as rather more consequence than as cause? My preference is to situate the cascading ecological revolutions of the early modern era within a more expansive competitive dynamic specific to the conditions of Europe's emergence from the socio-ecological crisis of the "long" fourteenth century—conditions that had as much to do with agrarian class structures and the Continent's state machineries as they did with concentrations of economic power. Over time (much less time than ever before), this emergent ecohistorical pattern, increasingly modern in its intensive and accelerating movements, led to the *relative* exhaustion of the relations governing the provisionally stabilized matrix of human and extra-human nature. Successive regional sugar complexes thereupon faltered as relative exhaustion undermined the conditions necessary to sustain a competitive position in the world market. Thence renewed the search for new, more fertile zones of production—from Madeira we move to São Tomé, Brazil, the Caribbean.

The rise of capitalism as world-ecology effected two world-historical ruptures of signal importance after 1450. The first rupture was centrally concerned with reworking time, the second, with revolutionizing space. First, *history moved faster.* Under the new regime, ecological wealth—from forests, fields, mines, and communities (qua labor power)—would be extracted in the quickest way possible. (Extracted, we should note, from these agrarian spaces and conveyed into urban-centered production and accumulation.) The rapid extension of commodity relations to frontier zones tended to produce, at first, great booms, and later, to undermine the socio-ecological conditions of production and therefore, eventually, the conditions of profitability. As with other leading commodity frontiers pivoting on silver, copper, iron, and forest products, successive sugar zones enjoyed their moment in the sun for but a short time. Typically, this was somewhere between 50 and 75 years. The contrast with the medieval Mediterranean is instructive. Sugar, cultivated on a large-scale in the Levant, Cyprus, and Sicily, evinced no strong tendency toward an accelerated cycle of boom, bust, and geographical relocation (Galloway, 1977; Solow, 1987; Verlinden, 1970). The movement was slower, incremental—in

other words, essentially medieval. This Mediterranean pattern was as different from the modern sugar complex as feudalism's settler colonialism was to Europe's overseas expansion.

This acceleration of historical process was inseparable from our second rupture, the expansion of the geographical arena. This was in fact the (slightly paradoxical) precondition for the geographical concentration of production on islands such as Madeira. A quantum leap in the production of time necessitated a quantum leap in the production of space. Madeira's sugar revolution was thinkable only through the successive movements of capitalist advance—in the direction of the Azores, the Canary Islands, São Tomé, and of course, West Africa.

Madeira's crisis coincided with massive deforestation. This much is certain. But correlation is not causation. It is not exactly news that sugar production and deforestation were intertwined. The geometrical representations we've reviewed provide a working hypothesis. But they are only suggestive, not conclusive. I do believe that fuelwood supplies constituted sugar's greatest vulnerability—on Madeira, to be sure, but not only on Madeira. It was a vulnerability common to the early modern sugar frontier in general (Moore, 2000b; 2007: ch. 6). Nevertheless, to focus on this or that moment of environmental change may fall wide of the mark. For the era's commodity frontiers—Brazilian sugar, Peruvian silver, Norwegian timber—rose and fell on the strength of the totality of socio-ecological relations governing commodity production, on the vitality of their *ecological regimes* (Moore, 2007; 2010a; 2010b). Thus, the crucial discussion turns on the exhaustion of the Portuguese Empire *as* ecological regime, and the erosion of that regime's capacity to compete effectively on the era's "vast but weak" world market, *itself a socio-ecological formation*. These themes I will pursue in Part II.

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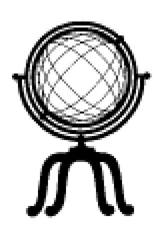
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Madeira, Sugar, and the Conquest of Nature in the "First" Sixteenth Century, Part II

From Regional Crisis to Commodity Frontier, 1506–1530*

Jason W. Moore

At the rosy dawn of sixteenth-century capitalism, few places in this "vast but weak" world-economy[1] were more pivotal than Madeira. A small island in the middle of the Atlantic Ocean, Madeira in 1500 was the greatest producer of early capitalism's most important cash crop, sugar. Every year between 1505 and 1509, some 2,000 tons of sugar flowed from Funchal, Madeira's capital, to Lisbon, Antwerp, Genoa, and many places beyond. Two decades later, the island's sugar complex had collapsed. Production in 1525 was barely 20% of the 1506 peak.

What happened? In the second of two articles in *Review*, I illustrate how the socio-ecological regime that enabled Madeira's sugar revolution between 1450 and 1500 ensured the rapid decline of production after 1506. As we explored in Part I (Moore, 2009a), this regime had everything to do with the forest. No cash crop devoured the forest so quickly as sugar. The island-wide disturbance of forest ecosystems was sufficiently serious that the first of several major extinctions of endemic mollusks occurred in the early sixteenth century, the result of "*rapid and large-scale change in the habitat, from woodland to grassland*" (Goodfriend, Cameron & Cook, 1994: 318, emphasis added).

If dwindling fuel supplies were sugar's greatest vulnerability, the sources of sugar's boom and bust on Madeira were irreducibly world-historical and multilayered. Whereas Part I focused

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[1] The phrase is Braudel's (1961).

on landscape transformations, in Part II of this essay, I trace the connections between *earth-moving* and the broader structures of capital and empire, above all the socio-ecological architectures of the world market and the Portuguese Empire in Braudel's (1953) "first" sixteenth century (c. 1450–1557). I begin by elaborating the relations between deforestation, soil fertility, and faltering labor productivity in agriculture as decisive to sugar's rapid decline. Far from a narrowly regional phenomenon, this rapid decline was not only caused, but indeed necessitated, by the rise of capitalism as world-ecology–a civilization that joins the endless conquest of nature and the endless accumulation in dialectical unity. Early capitalism, forged through successive commodity frontiers (sugar especially), was a structure of power committed to regional crisis as a way of life. In sum, regional socio-ecological crises were not merely resolved by commodity-centered frontier movements; they were also created by them.

HISTORICAL CAPITALISM AND REGIONAL CRISIS: FROM WORLD-ECONOMY TO WORLD-ECOLOGY

In what sense can we speak meaningfully of a "crisis" of Madeira's sugar complex? The salient facts are these. The sugar economy declined rapidly after 1510. From an average of 1900 tons in 1505–09, annual output declined to 1073 tons in 1515–19, to 835 tons in 1520–24, to 549 tons in 1525–29, to barely 300 tons in the 1530s. Production, peaking at 2480 tons in 1506, fell to 1180 tons in 1516, and just 467 tons a decade later. This collapse occurred in the midst of an improving world market for Madeira's producers. The real price fetched for Madeira's best grades of sugar increased by one-quarter between 1515 and 1517, and by 50% between 1515 and 1520, a price level that held more-or-less steady over the following decade (calculated from Pereira, 1969b; also Schwartz, 1985). New competitors emerged only after 1530. São Tomé, Madeira's eventual successor, struggled to export just 80 tons of low-grade sugar in 1529. Meanwhile, as we learned in Part I, the island's forests had receded sharply prior to the post-1506 *conjoncture*, and Madeira's slave population grew considerably after 1506. Although there were a succession of short-lived sugar revivals over the next century (Mauro, 1983), there would be no more sugar revolutions.

By 1546, Magalhães reports, "it is already written that 'most people on the island live by the vines'" (2009: 161). After the sixteenth century, most people knew Madeira for wine, not sweets.

We will presently explore Madeira's crisis in some detail. Before doing so, however, let me offer a consideration of this oft-used and undertheorized term, *crisis*. There were two novel, and specifically modern, features of this regional crisis in the decades after 1506. First, the pace of boom and bust on Madeira was unlike anything known in medieval Europe. Regional booms in feudal Europe unfolded through the necessarily sluggish movement of settler frontiers (Bartlett, 1993; Lewis, 1958; Moore 2003b; 2007). Commerce followed people in the Middle Ages. After 1450, *people* followed the commodity. By the "long" sixteenth century, medieval Europe's settler frontiers rapidly gave way to *commodity* frontiers. Urban-based capital was stymied within most of the European heartland during the first sixteenth century, thanks to the resistance of peasantries, urban guilds, and a patchwork of territorial and juridical formations. There were exceptions in this initial century of capitalist transition, especially in Central Europe's mining zones (Moore, 2007: ch. 2). On balance, however, urban-based capital looked abroad for new landscapes where the "original sources of all wealth" (land and labor) could be mobilized in servitude to the commodity form (Marx, 1976: 636–38). What lent this process of commodification a new urgency was the doubly competitive structure of the emergent capitalist order—inter-state and inter-capitalist competition.

This doubly competitive structure ensured that the rapid exhaustion of land and labor in the new commodity frontiers and the rapid expansion of Europe's territorial claims were mutually constituting processes. The second novel feature of regional crisis was therefore the global ecological fix. In other words, the modern conquest of time and the modern conquest of space were dialectically joined. Regional crises, after 1450, were those turning points through which a leading commodity complex yielded its systemic primacy. Sugar offers an especially clear case of this spatiotemporal movement. Madeira would give way to São Tomé, and then to Brazil and the Caribbean, over the next three centuries. It was not an all-or-nothing affair; *some* sugar was produced on Madeira throughout the early modern era. Rather, we are talking about the world-historical movement, through which new regional centers rise to (and then fall from) the commanding heights of the com-

modity sector in question. Sugar offers a paradigm instance of this process, but it was by no means alone.

I have drawn attention to commodity production and exchange, and capitalism is usually discussed in such terms. But this is only part of the picture. My preference is to situate commodification within the totality of capitalism's conditions of reproduction, a move that puts the messy relations between humans and the rest of nature front and center. In place of a Cartesian paradigm that sees "social" forces imposing their will upon an exogenous nature, I propose that we view the production of nature, the pursuit of power, and the accumulation of capital as an organic whole. This is the perspective of capitalism as *world-ecology* (Moore, 2003c; 2009a; 2009b; 2010a; 2010b; 2010c; 2011a; 2011b). Rather than blur distinctions within the organic whole, the world-ecological perspective refrains from the a priori designation of the "social" and the "environmental" and opens up the analysis of all forms of human experience to the interplay of human and biophysical natures. While this point has been powerfully argued on the terrain of social theory (e.g., Braun & Castree, 1998), the present argument is a brief for rethinking the great categories of world-historical social change—imperialism, commodification, social revolutions, and so forth—as socio-ecological projects and processes.

My point of departure is therefore the conditions of reproduction (the web of life) within which the generalization of commodity production and exchange takes place. For this reason I emphasize a theory of commodity frontiers that goes beyond the geographical extension of commodity relations (Moore, 2000b; 2003a; 2007; *pace* Cronon, 1991). Commodity frontiers were so extraordinarily effective in the rise of capitalism because the capitalization of socio-ecological relations was joined to the appropriation of nature's "free gifts" (Marx, 1967: III, 745). On these frontiers, a relatively small volume of capital, backed by territorial power, could appropriate a very large basket of nature's gifts. This explains the apparent paradox of sugar frontiers, especially where precocious forms of technological and institutional innovation took root in distant and seemingly "backward" regions (Mintz, 1985; Sheridan, 1969).

This epochal innovation was distinctive, but not limited, to sugar frontiers. Across the diversity of early modern commodity frontiers—timber, metals, fisheries, and cereals, from Brazil to the Baltic—a common pattern obtained. The defining feature was not

the absolute penetration of commodity relations, but the maximization of labor productivity through the appropriation of biophysical and human natures. This marked a radical reversal of feudalism's rules of reproduction. If *land productivity* governed the conditions for prosperity and poverty in feudal Europe, *labor productivity* was increasingly decisive in the capitalist world-ecology. Soil exhaustion and resource depletion were fundamental contradictions of the feudal order; under capitalism, these were irritations, signified by regional crises. These crises were quickly overcome through successive global ecological fixes, pioneered by the new commodity frontiers. Once labor productivity faltered in any given commodity complex, capital flowed elsewhere. Even in the first sixteenth century, we can glimpse the formation of Marx's law of value, through which labor productivity emerged as the metric of value for the modern world-system (Moore, 2009b; 2010c; 2011a; 2011b).

SUGAR, LABOR, AND THE FOREST: THE QUESTION OF SOIL EXHAUSTION

Madeira's ecological origin myth tells of a great fire that accompanied the earliest moments of settlement (Moore, 2009a). The "accidental" fire, for which human action was not responsible, was said to have lasted seven years, removing large parts of the island's forest cover. The resulting "destruction of Wood hath caused since a great want," Samuel Purchas clarified in the 1620s (1625: 6). As we saw in Part I, the "destruction of Wood" on Madeira was not accidental at all. It was a destruction propelled by a fuel-hungry sugar frontier that removed half the island's accessible forests by the early years of the sixteenth century.

Such myths are so powerful because they have a way of shaping what we see, and what we do not see. In the case of Madeira's origin myth, human action was cleansed from the story of forest destruction. This story meets up with an even grander, if more subtle, myth, operative in the historiography of sugar.

For much of the past two centuries, soil exhaustion has been regarded as a defining problem of the modern sugar complex. "Neither skill, nor capital nor abundance of labour have ever been found able to compete, in tropical cultivation, with the advantage of a new and fertile soil," Herman Merivale told Oxford audiences

in 1839–41 (1841: 298; also, *inter alia*, Galt, 1833; Williams, 1944; Dunn, 1972; Watts, 1987; Monzote, 2008). Soil exhaustion has certainly been an important reality. But there is also an important sense in which its significance has been mis-recognized, detached from labor productivity as the decisive element in competitive fitness. If soil exhaustion was a powerful force in the modern sugar commodity frontier, what kind of force was it? Was it an external barrier, as the historiography suggests, or was it rather endogenous, decisively mediated by the law of value? Capitalism cares little about soil fertility in itself. Its central concern is the productivity of labor in the service of commodity production.

At stake is the civilizational political ecology within which soil exhaustion operates—clearly an enduring problem for human civilization across the millennia (Montgomery, 2007). The historiographical emphasis on soil exhaustion establishes biophysical factors as exogenous, but this is true only in a supremely abstract way. Like Madeira's ecological origin myth, the soil exhaustion narrative tends to locate the source of modernity's problems in an exogenous and ahistorical nature. The latter, to be sure, acknowledges that human agents create problems with a nature that exists "out there," but elides the specific socio-ecological content of labor mobilization in historical capitalism. Soil fertility and exhaustion are in fact eminently historical relations internal to the capitalist mode of production. Far from washing away the "objective propert[ies] of the soil," such a reading reminds us that "fertility is not so natural a quality as might be thought; it is closely bound up with the social relations of the time" (Marx, 1967: III, 650; Marx, 1973: 141). The real socio-ecological barrier of capitalist production, as Marx might say, is capital itself (1967: III, 250).

The alternative is an optic that privileges labor productivity and thus the internalization of human nature within the capitalist world-ecology. For this reason, I have always valued Wallerstein's underappreciated formulation of "ecological exhaustion" (1980: 162). In this perspective, the mobilization and exhaustion of labor and land, human and extra-human nature, are dialectically bound (Wallerstein, 1974: 44, 89; Wallerstein, 1980: 132–33, 162n; Moore, 2007; Marx, 1976: 636–38). For Madeira in the first sixteenth century, it is probably best to situate such exhaustion within the broader ensemble of socio-ecological relations governing the island, and those obtaining within the Portuguese empire. This

recasts the crucial variable as one of the relative profitability of the *ecological regime*, rather than the apparent enormity of this or that moment of environmental change–soil exhaustion, deforestation, pest invasions, and so forth.

On Madeira after 1506, the chief problem was not soil exhaustion so much as it was the exhaustion of Madeira's ecological regime. This regime had sustained rising labor productivity during the sugar boom. There were two major pillars of high labor productivity, cheap inputs from the forest, and fertile soil. Both pillars eroded significantly after 1506, issuing declining productivity and aggregate production.

While canefields diffused across the southern half of the island in the half-century after 1450, the sugar mills (*engenhos*) did not. The *engenhos* remained geographically clustered around Funchal (Vieira, 2004: 57). Consequently, there was pressure to overexploit nearby forests; the hillsides surrounding Funchal were picked clean in the early sixteenth century (Vieira, 2009: 12). In 1519, the construction of new lime kilns–producing construction material–was banned on the grounds that they threatened "great loss" to the island's sugar producers (Magalhães, 2009: 161). By 1520, Funchal's residents were looking to Machico, in the northeast, for firewood and other timber "because it no longer remained in the [municipal] council's area" (Magalhães, 2009: 161).

Demand for fuelwood was consequently not generalized equally across the 30,000 hectares or so of commercially accessible forest. *Engenhos* were voracious consumers of fuel, consuming 60 kilograms of wood for every kilogram of sugar (Moore, 2009a). As mills were clustered geographically, they exhausted the woodlands nearby and close to waterways, and firewood had to be carted in from farther and farther away. As a result, there was an inexorable trend toward declining labor productivity for the most significant raw material (after cane) in the production process. True, Madeira is small, but carting was an expensive proposition, all the more so given the island's steep topography. More and more labor was necessary to secure the same amount of energy.

Deforestation was doubly problematic for Madeira's sugar complex. It wasn't simply that the forests supplied fuel for the boiling houses. Cane farmers depended on forest clearance, by means of organized (if not always contained) burns, to sustain labor productivity. Cleared forest served two functions. First, the creation

of arable land from the forest greatly enriched the soil, thanks to fertility bestowed upon it by "the black ash of the forest" (Bryans, 1959: 23; also Albuquerque & Vieira, 1988: 22, 27; Africanus, 1600: 56). The burned-over forest provided more than black ash. There was also a "yield honeymoon" provided by newly-cleared soils biologically unfamiliar with sugarcane (Dark & Gent, 2001). At first, new canefields enjoyed a respite from the greatest threats to labor productivity—weeds and pests. Early accounts of Madeira's colonization reported extraordinary yields, as high as 70:1 (Cadamosto, 1455: 9).

Madeira's honeymoon with sugar was over by the early sixteenth century. Leo Africanus, writing sometime between 1518 and 1526, drew a sharp contrast between the fertility of Madeira's early years and the decline of sugar. The sugar harvest "now . . . cometh not to one halfe of that [earlier] reckoning" (1600: 56). This sort of observation recurred throughout the early modern sugar frontier, in Brazil, Barbados, and Jamaica, as we saw in Part I (e.g., Lesley, 1740: 337).

Problems with soil fertility persisted. More than a century and a half later, the English merchant Ovington observed that:

> The Fertility of this Island is much abated from what it was in the Time of its first Plantation; and the continual breaking up of the Ground has, in many Places, impoverished its Productions; so that they are obliged to let it lie fallow for three or four Years: After which Time, if there springs-up no Bloom, they conclude it is quite barren (1696: 18).

Monoculture achieved short-run gains by simplifying the land (the object of labor) as a means of maximizing labor productivity. Over the middle-run of three decades, this monocultural strategy was progressively self-limiting. As the forest receded, it became difficult to expand arable land through renewed forest clearance. This clearance, as we have seen, attenuated monoculture's encouragement of weed and pest problems. The result was an upward spiral of pestilence. Weeds in early modern plantation agriculture enjoyed a dramatic, non-linear growth curve (Watts, 1985), and were probably the most powerful vector of soil exhaustion. They also proved a formidable drag on labor productivity. In eighteenth-century Brazil, weeding consumed as much labor as the grueling

tasks of cutting and carting cane, *combined* (Schwartz, 1985: 142; for eighteenth-century Barbados, see Roberts, 2006).

Sugarcane created yet other biological competitors. In 1502, caterpillars ravaged canefields across the island. It was the first of many pest invasions (Koebel, 1909: 128; Mauro, 1983: 207; Duncan, 1972: 32; Rau, 1964: 5). Mauro is prepared to go still further. The caterpillar invasions that began in earnest after 1502 "attacked [not only] the canes, [but also] the manpower" (1983: 206). Nor were caterpillars the only pests. There was also the "struggle against rats, against which the slaves were deployed with all their diligence" (Mauro, 1983: 207). Such multiform pestilence became a recurrent feature of the sugar commodity frontier. In São Tomé just two decades later in the 1520s—and just three decades after sugar cultivation commenced on the island—so-called ship rats, unintentionally imported from Europe, had "mightily impaired the growth of this commodity," for a time cutting export volume by 85% (Africanus 1600: 53; Dutton, 1994: 928).

These countervailing forces created by King Sugar "impoverish[ed] . . . the soils" on Madeira by the early sixteenth century, "inevitably reduc[ing] . . . productivity capacity" (Pereira, 1969b: 158, 220; also Pereira, 1969a: 484, 462). The most dramatic expressions of this trend were found in the captaincy of Funchal, where sugar cultivation began on the island. In contrast, Machico to the northeast declined much more slowly, a difference that Albuquerque and Vieira explain in terms of the relative soil fertility (1988: 29).

SUGAR, SLAVERY, AND LABOR PRODUCTIVITY

> Most of the Islands inhabited by the Portugals, especially those of Saint Thomas and Madera, besides the Portugals themselves, containe a great multitude of Negro-slaves, brought thither out of Congo and Angola, who till the earth, water the sugar-canes, and serve both in the cities, and in the countrie.
>
> —Leo Africanus, c. 1518–26 (1600: 417)

To the paradox of rising prices and falling production, we can add the paradox of increasing slave imports and decreasing sugar output. The evidence is not what one would wish. While there is some evidence on patterns of slaveholding (Vieira, 1996), we have

neither good figures on annual slave arrivals nor on slave mortality.

We do, however, have reliable estimates of Madeira's slave imports during its sugar revolution and subsequent crisis. Even working from a highly conservative reckoning of slave population—one that overstates slave productivity—the result is a curious sort of Kuznets-curve, one characterized by sharply rising, then rapidly declining, labor productivity. It is precisely what one would expect from a sugar revolution capitalizing on a yield honeymoon, followed by a strong socio-ecological pushback. As fields were exhausted or plagued with pests and weeds, as woodland receded, ever more labor was required to maintain output.

How much labor did it take to cultivate and process 1,000–2,000 tons of sugar? I begin with Barrett and Schwartz's estimate of slave productivity for sixteenth-century Brazil (1975: 542)—the middle range of which is .33 tons per labor-year (also see Moore, 2007: 260; Blackburn, 1997: 205). With this reckoning, the 1680 tons Madeira produced in 1498 required the full-time labor of 5,040 unfree cultivators and technicians.[2] This is a generous estimate for slave productivity, more than 25% higher than the prevailing average in 1680 Barbados.[3] Of course, Madeira was not a slave colony on the model of seventeenth-century Barbados (Vieira, 1996; 2004). Vieira tends to minimize the role of slavery during Madeira's sugar cycle, but it is difficult to see how the island could have produced so much sugar otherwise (Greenfield, 1977). Blackburn thinks that

[2] There are two principal ways to measure slave productivity. One is at the level of the individual, the other at the level of the social economy. When Deerr (1949: 101) puts slave productivity for seventeenth-century Brazil at 60 arrobas (1940.4 lbs), we are looking at the productivity within the cultivation process itself, hived off from processing, and also (no less crucially) from transport and distribution (also Taylor, 1970). The measure of slave productivity that I am using seeks to illuminate Madeira's social ecology as a whole.

[3] Whether or not labor productivity was substantially higher in the West Indies remains an open question. Looking at Antigua, St. Kitts, Montserrat, and Nevis in the 1770s—which together produced 21,158 tons (as much as Brazil in 1700)—Deerr's figures indicate a range of labor productivity between .198 tons/slave (Antigua) and .39 tons/slave (St. Kitts), with an average productivity of .26 tons/slave (for 82,270 slaves) (all calculated from Deerr, 1949: 174). This was roughly the same in Barbados c. 1680. The island produced about 10,000 tons of sugar (1683) with 38,782 slaves (1680), which yields a level of productivity *exactly* the same, .26 tons/slave, as calculated from, respectively, Dunn (1972: 203) and Galloway (1989: 81). Schomburgk, drawing on contemporary reports, thinks the number of slaves was significantly higher, 46,602 in 1683–84 (1848: 82), which would have depressed labor productivity still further.

some 2,000 slaves worked on the island at the end of the fifteenth century, "mostly" in sugar (1997: 109).[4]

Was the supply of slaves sufficient to sustain sugar's rising labor demands? Between 1450 and 1500, 17,500 African slaves were shipped into the northern Atlantic islands (Rawley & Behrendt, 2005: 20).[5] The figure excludes São Tomé and Europe. If we assume that 10,000 of these workers (60%) were destined for Madeira, and that most of them (90%) arrived after 1470, this put annual imports between 1470 and 1500 at 300. Klein is more cautious, estimating annual slave arrivals at 200 in 1476–1525 (2004: 203). Given sugar's labor demands, this estimate strikes me as a theoretical minimum.

At this point, we are again pushed back to a quantitative reckoning. We can make three assumptions about the slave population on Madeira, all of which minimize declining labor productivity: 1) very modest annual slave imports (200); 2) very high slave mortality (5%);[6] and 3) the complete absence of slaves in 1475. Even with these caveats, slave population increased very quickly, to 2,054 by 1488, and to 3,000 by 1500. Productivity, through 1509, increased even more markedly, moving from .37 tons/slave to .57 tons in the two decades after 1489. Thereafter, as we see in table 1, the trend is sharply downward. In the two decades after 1509, labor productivity fell from .57 tons to .15 tons/slave.

More and more labor was required to extract wealth from external nature. The foregoing estimates bear only an indirect relation to the reality they seek to illuminate. Naturally, many unfree workers were involved in other activities, including the vineyards that began to supplant canefields in a big way after 1520; free labor was mobilized widely, and there were many small cultivators who had just one or two slaves. And yet, a growing number of slaves entered

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[4] An additional 1500 workers cut and hauled wood. This is a deliberate underestimate. I've calculated that one woodcutter was necessary for every 1.62 tons of sugar. I have calculated on the basis of the new arroba (32.34 lbs.), from the number of woodcutters in Bahia in the 1750s (4000), and the region's sugar output in 1758 (400,000 arrobas) (Miller, 1994: 184; Schwartz, 1985: xxiii, 423).

[5] Building on Elbl's estimates (1997) and Curtin's geographical distributions (1969).

[6] Viewed from the *longue durée* of the sugar frontier, slave mortality was rarely higher than five percent, with a few gruesome exceptions to be found in the eighteenth-century Caribbean—abstracting, of course, the horrific mortality of the Middle Passage itself (Moore, 2007: chs. 5, 6).

Madeira after 1475. The trend was toward more, not fewer, slave arrivals: In the 1550s, some 300 slaves landed in Funchal every year (Mauro, 1983: 206). With so many slaves arriving, how was it that a "labor shortage" afflicted the island, dating from the 1520s (Vieira, 2004: 48)? At least 3,700 slaves lived on Madeira by 1525, when sugar output was less than one-quarter of its 1506 peak. True, the economy was reorienting toward vines, and estate formation in viniculture could be labor intensive. Does this explain a situation of labor scarcity? Perhaps in part; but at the same time, is it not more plausible to account for this tightening labor market *primarily* in terms of the political ecology of declining labor productivity in the sugar sector? In the *conjoncture* of 1510–30, planters were seeking to maintain output in an agro-ecological environment of dwindling fuel resources and declining soil fertility, and in a market environment of rising sugar prices.

Table 1
Sugar, Slavery, and Labor Productivity on Madeira, 1475–1529

	Slave Population	Sugar Production	Productivity (Annual)
1489	2151	800 tons	.37 tons/slave
1499	2892	1200 tons	.41 tons/slave
1504	3142	1500 tons	.47 tons/slave
1509	3337	1900 tons	.57 tons/slave
1519	3602	1073 tons	.3 tons/slave
1524	3692	835 tons	.23 tons/slave
1529	3762	549 tons	.15 tons/slave

Sources: Klein (2004); Moore (2007); Pereira (1969b).

LABOR, SOIL, AND THE FOREST: ACCOUNTING FOR MADEIRA'S RAPID DECLINE

The squeeze on soil fertility and labor are compelling factors in accounting for Madeira's decline. But I don't think they explain the *speed* of that decline. Viewed in comparative perspective, declin-

ing soil fertility—barring catastrophic episodes of soil erosion—was unlikely to issue such a sharp decline. There were mechanisms to counteract the tendency toward declining soil productivity. Madeira's soils were already manured (Galloway, 1989), and more could be brought in; pest invasions could be severe, but tended to produce sharp and episodic production shortfalls; the evolution of weeds was a major problem, but one that could be addressed by putting more men on the job.

The exhaustion of the forest was the only thing that could not be fixed. Fuelwood demands were simply too great, the island too small, the economics of transport too unfavorable. Recall that amongst the motivations of Madeira's initial colonization was the quest for timber, and that sixteenth-century Portugal was wracked by growing timber supply problems (Devy-Vareta, 1986; Pinto, Aguiar & Partidário, 2010). Labor, capital, food, livestock—all could be shipped into Madeira as needed, so long as the economics of the situation allowed. Fuel was the one item that could not be easily secured from abroad.

The world market remained quite favorable for Madeira's sugar. The paradox is that Madeira's boom played out in a period of falling sugar prices, while its crisis unfolded in an era of rising real prices. During the island's boom, sugar prices declined from an average of 725 *reais* per arroba in 1469 to 475 *reais* in 1496 (Rau, 1964: 9; also Vieira, 2004: 62). In England, sugar's price declined 75%—and in France by a little more—over the course of the fifteenth century (Edel, 1969: 26; Taylor, 1978: 14). The nadir was the depression of 1497–99, a genuine overproduction crisis. But it was short-lived. Recovery and thence renewed expansion was quick (Albuquerque & Vieira, 1988). How was this possible? The sugar revolution's yield honeymoon depressed the costs of production faster than market prices fell.

After 1500, Madeira's sugar enjoyed stable, even rising, prices (Pereira, 1969b; also Garfield, 1992: 65). Measured in gold, the price of sugar increased 460% on the London market between 1501 and 1540, although in real terms not so sharply (Simonsen, 1957: 143). Demand for the island's sugar was also consistently high in Antwerp, where prices were rising through the first half of the sixteenth century (Harreld, 2003: 151). In contrast to the spice trade, sugar enjoyed steadily rising real prices in the sixteenth century, increasing .44% per annum until 1550, and .53% over the next

half-century (O'Rourke & Williamson, 2002: 446–48). All of this indicates that the rising price of sugar was no artifact of the Price Revolution, which had its origins in the European silver mining boom of the 1460s, accelerating strongly after 1520 (Braudel & Spooner, 1967; Munro, 2003; Moore, 2007: ch. 2).

If São Tomé or Brazil had been the culprit of this decline, we would expect to see major exports from these zones toward the beginning, not the end, of Madeira's crisis. São Tomé, however, became a major producer only in the 1540s. In 1529, São Tomé exported just 80 tons a year, although this would increase thirty-fold by 1555 (Hodges & Newitt, 1988: 20; Garfield, 1992: 72). In any event, Madeira and São Tomé did not produce the same grade of sugar. Madeira's sugar was prized for its high quality, quality that was won by additional phases of fuel-intensive processing (Vieira, 2004; Pereira, 1969b). In contrast, São Tomé's competitive edge was quantity, not quality; its sugar was of notoriously low quality (Garfield, 1992: 64–65; Harreld, 2003: 152–53). As for Brazil, its output matched São Tomé's by the 1560s, reaching 2,654 tons annually in that decade (Simonsen, 1957: 172–73; Hodges & Newitt, 1988: 20), but this was a half-century removed from Madeira's crisis.

MADEIRA'S CRISIS IN THE EXHAUSTION OF PORTUGAL'S FIRST IMPERIAL ECOLOGICAL REGIME

Madeira's crisis was hardly isolated within the Portuguese Empire. For Pereira, the half-century between 1475 and 1525 was one of an "urgent" imperialism characterized by the Empire's "excessive demand" for natural resources. At the beginning of this era,

> it was possible to find the necessary ingredients for global expansion: men, skills, motivation and strategic raw materials. The activation of the resources of the realm *and the islands* continued to be pursued, with a paradoxical exhaustion of these same resources in all spaces. Until the end of the period, no serious ruptures were to be noticed, whether in demographic terms, in the renewal of the labor force, or in terms of raw materials. . . . [By the 1520s, however,] the first signs of the exhaustion of strategic raw materials began to appear, particularly wood and metals, as well as the

> lengthy and difficult processes of renewal and extraction (2006: 10, 12, emphasis added).

A precocious "monarchical capitalism" that pioneered the capitalist Atlantic (Dias, 1967; Wallerstein, 1974), the Portuguese Empire was also at the cutting edge of world-ecological change. Elsewhere in Europe, the demographic contraction of the "long" fourteenth century had given the Continent's forests some breathing room (Williams, 2003). Not so in Portugal. The second half of the fifteenth century inaugurated an era of "intense deforestation" in Portugal, characterized by escalating conflicts between agro-pastoral, peasant, urban, and manufacturing interests (Pinto, Aguiar & Partidário, 2010: 20; Devy-Vareta, 1986; 2007). As a result, Portugal's forest woes materialized a century before those of western Europe, and decades before Spain's (Moore, 2010a; 2010b). Just as deforestation on Madeira materialized several waves of species extinction, the new wave of forest appropriations registered the extinction of the red squirrel (*Sciuirus vulgaris*) within Portugal by the late sixteenth century (Goodfriend, Cameron & Cook, 1994; Mathias & Gurnell, 1998).

Within Portugal, fuelwood was increasingly expensive, and this influenced the geography of sugar refining within Europe. While the initial processing of cane had to take place on Madeira, further refining was increasingly relocated beyond the island, first to Lisbon, and then to Antwerp. By 1496, one-quarter to one-third of Madeira's sugar was marketed by Flemish capital, a volume of sugar six times greater than Portugal's net sugar inflow (Furtado, 1963: 8; Birmingham, 2000: 13; Taylor, 1978: 16). Fuel-intensive clarification and refinement began to concentrate in northwestern Europe. The recentering of sugar refining indicates a situation of rising fuel costs not only on Madeira, but also in Portugal, relative to northwestern Europe. While the maritime Low Countries were also sparsely forested, urban manufacturers such as sugar refiners could access abundant peat (Zeeuw, 1978).

Alas, Lisbon enjoyed neither coal nor peat. In 1559, the Crown prohibited sugar refining in Lisbon because its fuel demands threatened the supply of shipbuilding timber (Mauro, 1983: 272). The 1559 prohibition on sugar refining was issued at the very moment when the Crown was taking other measures to preserve forest resources, when Madeira's sugar complex was but a shadow of its former self, and when the Mediterranean world as a whole was

in the midst of a "timber crisis" (Braudel, 1972: 143; also Cipolla, 1976: 228–30). While sugar did not demand high-quality timber, in Portugal as throughout early modern Europe, such timber was nevertheless widely used as fuelwood. The political ecology of Europe's forests was dominated by an endemic (and chaotic) "battle for wood" (Devy-Vareta, 1986; Goodman, 1997; 1998; Moore, 2007; 2010a; 2010b; Westermann, 1996). In 1565 the Portuguese Crown imposed a "Law of Trees" and would initiate various tree planting schemes over the next few decades (Devy-Vareta, 1986). Barros reports that "mentions of timber shortages [began to appear] ... in Lisbon by the end of the sixteenth century,"[7] a situation that persisted until well into the eighteenth century (Mendes, 2004: 83; also Pinto, Aguiar & Partidário, 2010).

Signs of Braudel's timber crisis were apparent across Mediterranean Europe. Madeira's crisis was surely one contributing factor in the exhaustion of Portugal's first imperial ecological regime by the 1520s. If Portugal ran into trouble somewhat earlier than the rest of this "macro-Mediterranean" (Mauro, 1992: 103), is this not explicable by its head start in overseas expansion? Not just Portuguese, but also Spanish shipbuilding was "in a state of crisis from the 1560s on" (Phillips, 1986: 22; also Moore, 2010a). Philip III (Portugal's Felipe II; r. 1598–1621) would be warned by a senior naval commander that "those lands [within Portugal] that produce wood *should be guarded like the Potosí hills*" (quoted in Barros, 2005: 11, emphasis added).

This timber crisis turned on the capacity of the European Mediterranean's forest regime to sustain a competitive position relative to the North Atlantic. This was about more than forests, to be sure, but cheap and reliable flows of forest products were central to the era's competitive struggles. It is also true that the region's forests did not disappear. Even in the famous case of the Venetian Republic, absolute scarcities of forest products rarely occurred (Appuhn, 2009). The crucial geohistorical shift was found in the ways that the global fixes of the capitalist world-ecology were implicated in the rise of the "capitalist North Atlantic" and the decline of the "global" Mediterranean (Moore, 2010a; 2010b; Braudel, 1972). The relocation of shipbuilding centers and leading commodity frontiers—such as sugar planting—were dialectically bound. On the one

[7] Amândio Jorge Morais Barros, of Instituto de Historia Moderna da Universidade do Porto, personal communication with the author, June 14, 2006.

hand, the Mediterranean crisis allowed northwestern Europeans to capture not only the high-profit activities of the sugar complex (refining and marketing), but also the high-profit lines of shipping and shipbuilding. Whereas Southern Europe's share of European fleet capacity was 40% in 1500, by 1780 it had fallen to 15% (Zanden & Horlings, 1999: 36; Unger, 1992: 260–61). Portugal would be building ships in Bahia (Brazil) and Goa (India) by the seventeenth century (Morton, 1978; Özveren, 2000).

MADEIRA IN THE RISE OF THE CAPITALIST WORLD-ECOLOGY

It is dangerous to read too much from the experience of small islands, even when the islands in question are "as important as continents" (Mauro, 1961: 4). But it would also be unwise to read too little. Madeira's sugar revolution was one of several decisive points of fracture in the early transition from feudalism to capitalism. Taken in isolation, any of the factors identified in these two essays can be explained away as essentially non-capitalist. The shift in property relations mandated a "weak" rather than "strong" compulsion toward rising productivity. The movement toward modern plantation slavery was modest at best. The pace of landscape transformation was rapid, but Madeira was a small island. The growth of sugar production on Madeira outstripped its medieval forerunners, but remained a far cry from the rivers of sugar that flowed from Brazil and the Caribbean in subsequent centuries.

Taken as a whole, however, these multiple ruptures with medieval patterns suggest that something new was taking shape. Perhaps most telling, the crisis of Madeira's sugar complex did not provoke a collapse of world sugar production. Capital and expertise flowed from Madeira to new frontiers, above all to São Tomé, and later Brazil. For Madeira was but one leg of a great frontier journey, sustained by the endless search for new opportunities to appropriate nature's free gifts, gifts that included human nature no less than fertile soil and abundant forests. Nor was Madeira exceptional. The frontier movement toward São Tomé, accomplished by the 1550s, was bound with a broader movement of global ecological fix. The turbulence of the mid-sixteenth century, punctuated by the 1557 financial crisis and dramatized by recurrent state

bankruptcies throughout western Europe, were linked with a system-wide revolution in the relations between humans and the rest of nature. Northern Europe's timber frontier shifted from Poland to Norway (Malowist, 1960; Moore, 2010b); the center of silver production moved from Central Europe to Peru (Moore, 2010d); the copper frontier moved from Slovakia to Sweden (Moore, 2007: ch. 2). These were pivotal moments in the world ecological revolution of the "long" seventeenth century (Moore, 2010a; 2010b). If regional shifts were nothing new, before the sixteenth century never had these frontiers moved so rapidly, and across such vast spaces.

What accounts for this rupture with medieval patterns? In a word, commodification. Sugar, of course, had long been a commodity produced for long-distance trade. But after the 1450s, as we see in Madeira, production for the market was joined to the commodification of land and labor. This triple helix of commodification—sugar, land, and labor—explains the competitive dynamism of successive sugar revolutions across the early capitalist Atlantic, and with it, the rapid exhaustion of the local conditions necessary to sustain such dynamism. Regional commodity revolutions owe their "revolutionary" character to the scale and speed with which capitalist and territorialist agencies appropriate nature's free gifts. On Madeira, the greatest of these free gifts were derived from the forest and the soil. At some point in the early sixteenth century, the opportunities for appropriating these original sources of wealth contracted. Rising fuel costs intersected with soil exhaustion to undermine the socio-ecological basis of labor productivity. Market demand for sugar remained favorable for many decades to come. Indeed, it was more favorable than during the boom years of the late fifteenth century. The Crown even cut taxes in the midst of the crisis (1515), but to no avail (Magalhães, 2009: 159).

In the end, nothing could overcome the Portuguese Atlantic's sylvan poverty. Given the slow regeneration of the forests, we would expect to see an industry dependent on rapid forest exploitation to expand quickly and collapse precipitously. We might then expect to see periodic, but short-lived, revivals of that sector, given favorable price movements and some measure of forest regeneration. And this is just what we see. Madeira experienced short-lived sugar booms over the next century (Mauro, 1983). But it never again scaled the commanding heights of the world sugar economy, which is, after all, the point. Early capitalism's boomtown regions were

vast and varied, precisely because this ecological regime depended on the endless conquest of the earth to sustain the endless accumulation of capital, the real basis of which was labor productivity.

Beginning in this first sixteenth century, regional crises were resolved through global expansion, the global ecological fix (Moore, 2010a; 2010b; 2011a). Given sugar's biophysical particularities and therefore the limited possibilities for expansion within Europe, the global ecological fix entailed overseas expansion—and not merely expansion as event. The "long" sixteenth century was defined by *expansion as permanent movement*. The political ecology of competition on the world market, emerging in turns spectacularly and tentatively, underpinned the secular tendency toward regional socio-ecological exhaustion. This moved Europe's civilizational expansion from an occasional episode to a way of life. Between the 1530s and the 1670s, Europe's territorial and capitalist powers extended their geographical hegemony from three to seven million square kilometers (Chaunu, 1959: 148). The sugar commodity frontier was not responsible for all of this, but little of it was conceivable without sugar and its triple helix of commodification.

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